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PSEUDO-EUTECTIC TEXTURES.[1]

WALDEMAR LINDGREN.

THE peculiar intergrowths of sulphide minerals which more or less closely simulate the eutectic texture in metals have been known for some time and have been the subject of many papers and discussions. The one earliest observed and described was formed by bornite and chalcocite. Originally described by Laney,[2] it was later discussed by Segall,[3] by Whitehead,[4] by Rogers,[5] and by Guild.[6] The latter three authors regard the texture as a replacement of bornite by chalcocite, while Laney interpreted the same texture as due to contemporaneous deposition.

Since then opinions have differed. The majority of authors, lately represented by Locke, Short and Hall,[7] and by Short and Ettlinger,[8] still appear to regard the texture as one indicating simultaneous deposition.

The writer has consistently held that the intergrowth indicates replacement and has expressed this view several times.[9]

[1] Contribution from National Research Council Committee on Processes of Ore deposition, sub-committee on Criteria of Paragenesis of Ore Minerals, E. S. Bastin, Chairman.

[2] Laney, F. B., ECON. GEOL., vol. 6, pp. 399–411, 1911.

[3] Segall, Julius, *idem*, vol. 10, pp. 462–470, 1915.

[4] Whitehead, W. L., *idem*, vol. 11, pp. 1–13, 1916.

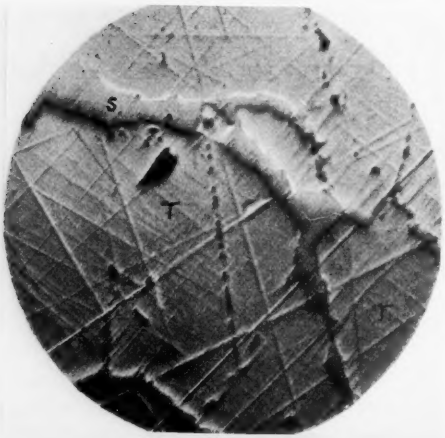
[5] Rogers, A. F., *idem*, vol. 11, pp. 582–593, 1916.

[6] Guild, F. N., *idem*, vol. 12, pp. 297–353, 1917.

[7] Locke, Augustus, Short, M. N., and Hall, D. A., *Trans. Am. Inst. Min. & Met. Eng.*, 70, pp. 933–963, 1924.

[8] Short, M. N., and Ettlinger, I. A., *idem*, 74, pp. 174–222, 1926.

[9] Lindgren, Waldemar, "Mineral Deposits," pp. 209, 926, 1928.



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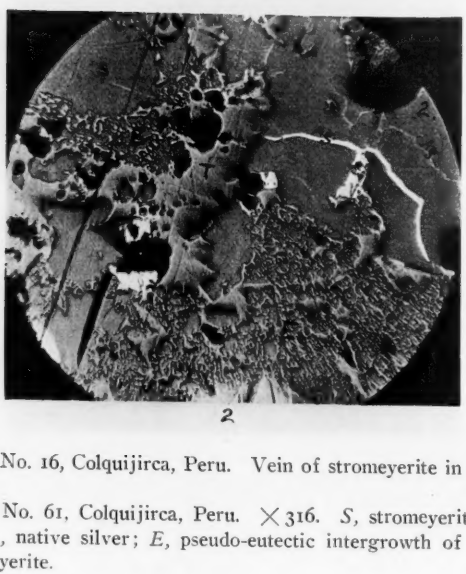

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FIG. 1. No. 16, Colquijirca, Peru. Vein of stromeyerite in tennantite. × 540.

FIG. 2. No. 61, Colquijirca, Peru. × 316. *S*, stromeyerite; *T*, tennantite; *ag*, native silver; *E*, pseudo-eutectic intergrowth of tennantite and stromeyerite.

It seemed desirable to select a suitable case for a critical study of the pseudo-eutectic texture. The minerals should not be too closely related, like bornite and chalcocite. At least one should react strongly on polarized light so that its texture might be ascertained. The minerals should be definitely identified.

Such a case was found in a suite from the Colquijirca silver mine near Cerro de Pasco, Peru, submitted to me by the owner, Mr. E. E. Fernandini. The intergrowth was of tennantite and stromeyerite. Two analyses were made of the tennantite and one of the stromeyerite, and they correspond to the formulas $Cu_6As_2S_6$ and to $(Cu, Ag)_2S$. The tennantite contains as much as 5 per cent. Ag. and some Bi and Zn. The stromeyerite contains about 2 per cent. Bi.

Generally speaking there seems to be substantial agreement among geologists that stromeyerite is later than tennantite; in fact, the most prevalent opinion is that stromeyerite is of supergene origin. This is held by Guild,[10] who has described a somewhat similar case where stromeyerite replaces tetrahedrite.

Description of Textures.—The proportion of tennantite to stromeyerite varies greatly in various sections: Sometimes one, sometimes the other is in large excess. The pseudoeutectic texture is not always present. Even in the same photograph some tennantite may appear with "mutual boundaries" against stromeyerite, or again it may be replaced by stromeyerite in well-defined veinlets of wholly irregular direction (Fig. 1). The latter figure is taken from Sp. 16 in which stromeyerite (analysis from this specimen) so replaces both chalcopyrite and tennantite. In that same section there are, however, areas in which the pseudoeutectic intergrowth is locally present though not extensively, or particularly well-developed. At any rate it certainly is proved that some of the stromeyerite is later than the tennantite.

The general appearance of sections from Sp. 61 is shown by Fig. 2. The specimen consists of a silicified rock, probably originally a calcareous shale, now a mass of crypto-crystal-

[10] Guild, F. N., "A Microscopic Study of the Silver Ores and their Associated Minerals," ECON. GEOL., vol. 12, pp. 297–353, 1927.

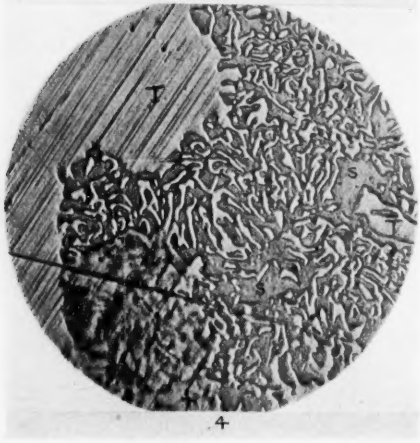
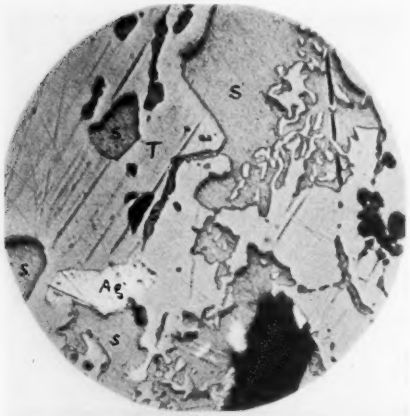


FIG. 3. No. 61, Colquijirca, Peru. *S*, stromeyerite; *T*, tennantite; *Ag*, silver. Veinlet of stromeyerite projecting in tennantite. Active contacts advancing with stromeyerite convex against tennantite. × 446.

FIG. 4. No. 61, Colquijirca, Peru. *S*, stromeyerite; *T*, tennantite. × 446. Note straight fronts of advancing stromeyerite. Attacking tennantite in curves, convex towards latter.

FIG. 5. No. 61, Colquijirca, Peru. *T*, tennantite; *S*, stromeyerite; silver; *S* + *T*, pseudo-eutectic areas. × 460.

FIG. 6. No. 61, Colquijirca, Peru. × 460. Veinlike advance of stromeyerite in tennantite, *T*.



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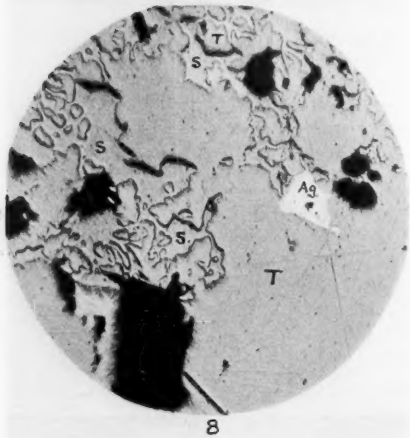

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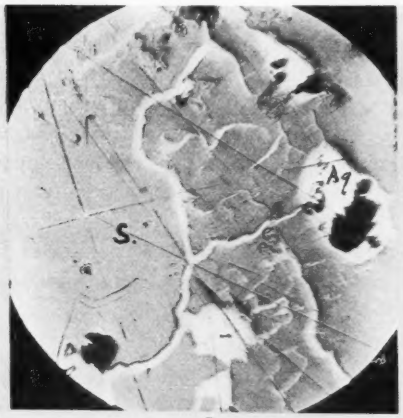
FIG. 7. No. 61, Colquijirca, Peru. Stromeyerite, *S*, projecting as veins in tennantite, *T*. Contacts smooth in part, in part showing pseudo-eutectic residuals of tennantite. × 426.

FIG. 8. No. 61, Colquijirca, Peru. × 426. Replacement of tennantite *T*, by stromeyerite, *S*, showing smooth boundaries and veinlets of latter, with pseudo-eutectic areas poorly defined.



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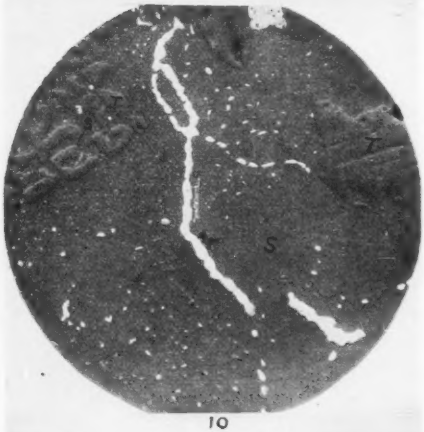

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FIG. 9. No. 61, Colquijirca, Peru. Silver, *Ag*, in stromeyerite mainly following outlines of stromeyerite grains. × 270.

FIG. 10. No. 61, Colquijirca, Peru. × 460. Veinlets of silver, *Ag*, separating into dots. Clouds of dots and dashes of *Ag* in stromeyerite. *T*, tennantite.

line silica. This is traversed by a series of thin parallel veinlets, evidently the result of sheeting, each one rarely more than one millimeter thick. Sections parallel to these veinlets show tennantite, chalcopyrite, stromeyerite, and native silver.

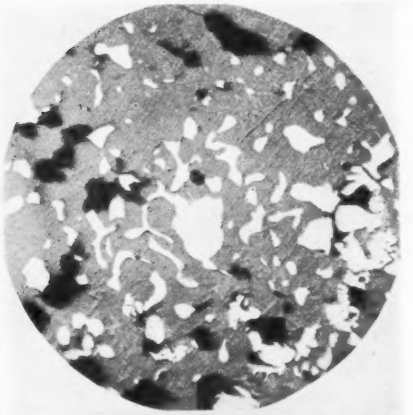
Tennantite occurs in large grains. Stromeyerite, which has a very strong action on polarized light, likewise appears as large grains. Any given area of pseudo-eutectic intergrowth is made up of one to several such large grains, and the parallel orientation extends over considerable areas. The contacts of the two minerals are of varying appearance; sometimes they are straight or they may be of the "mutual" kind (Fig. 5). Sometimes there is no well-defined pseudo-eutectic but the stromeyerite develops in curving or straight veinlets (Fig. 8) accompanied by a poorly developed pseudo-eutectic. Areas of intergrowth may be connected by veins of a texture approaching pseudo-eutectic (Fig. 6). Undoubted veins of stromeyerite are illustrated in Figs. 1, 3, and 7.

Sometimes again pseudo-eutectic areas, typically illustrated in Fig. 4, border against tennantite by fairly straight lines but when examined in detail it is seen that the stromeyerite proceeds against the tennantite in a series of convex curves. This to my mind is one of the best criteria of replacement.

All these figures from 2 to 10 are taken from one and the same veinlet in the specimen, and from one and the same polished section. When proceeding normally the pseudo-eutectic is uniform over considerable areas, but doubtless its development is locally influenced by structural features, such as contacts, cracks, or possibly cleavage.

KNOWN PSEUDO-EUTECTIC TEXTURES.

In the preceding pages I think that cogent proofs have been presented to show that in the pseudo-eutectic texture of tennantite-stromeyerite the latter mineral replaces tennantite. It might now be well to examine a little further into general facts relating to such intergrowths.



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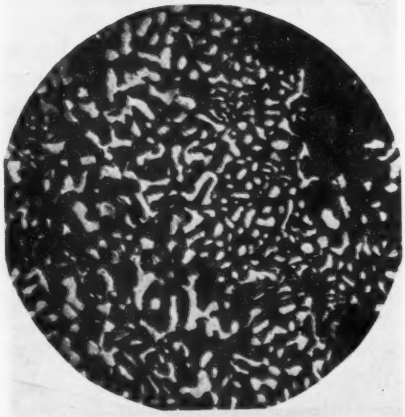

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FIG. 11. Pseudo-eutectic texture of sphalerite (dark) and galena (light). Parral, Mexico. × 200.

FIG. 12. Pseudo-eutectic texture of sphalerite (dark) and chalcopyrite (light). Parral, Mexico. × 200.

Pseudo-eutectic textures have been observed in the following cases, the replacing mineral in all cases being mentioned last.[11]

Bornite-chalcocite (Laney),
Bornite-chalcopyrite (Van der Veen),
Bornite-galena (Short),
Bornite-stromeyerite (Guild),
Galena-stromeyerite (Guild),
Galena-tennantite or tennantite-galena (Lindgren),
Galena-proustite (Guild),
Tennantite-stromeyerite (Lindgren),
Tennantite-chalcopyrite (imperfect),
Sphalerite-chalcopyrite (Fig. 12),
Sphalerite-galena (imperfect) (Fig. 11).
Tetradymite-altaite (Thomson).

Hardness.—In all cases except the last the replaced mineral is isometric. This may have some significance. Of more interest is the apparent fact that all of these minerals (replaced or replacing) are soft minerals with hardness below 4 (in most cases below 3). No cases of pseudo-eutectic texture are known of harder minerals, such as pyrite, magnetite, specularite, or arsenopyrite.

GENERAL HYPOTHESIS.

It is believed that in all cases the pseudo-eutectic texture represents a replacement of one soft mineral by another. In its typical development this texture is independent of structural lines in the host. Occasionally (chalcocite after bornite) the cleavage of the host may determine elongations, but this is unusual. Cracks, joints, or fissures do not influence the replacement except quite locally. It is believed that this texture is the normal result of replacement in a (for practical purposes) homogeneous medium; the replacement progresses equally in all directions, resulting in residual areas of the host having curved, club-like or hook-like forms. The replacement of hard host minerals like pyrite results

[11] The intergrowth of arsenic and antimony has not been considered. It presents some features which seem different from those here discussed.

usually simply in rounded residuals. In other cases like galena after sphalerite, the resulting residual forms are irregular, with more or less approach to pseudo-eutectic texture.

Essentially it calls for a compact uniform host mineral and it would seem probable that most of these replacements must take place under considerable load and not at low temperature; in other words, they are probably hypogene.

Another feature, which is certainly characteristic of the chalcocite and stromeyerite replacements, is that the invading mineral has the same orientation over large areas. That was shown by Laney in case of the intergrowths of chalcocite and bornite from Vigilina, and it is certainly true of the intergrowth of tennantite and stromeyerite described above. Where the guest mineral assumes a micro-crystalline structure there are no pseudo-eutectic intergrowths.

Locally either of the minerals may be in excess. There are all transitions from typical pseudo-eutectic texture to irregular residual remnants.

The hypothesis advanced by Prof. Graton in lectures that this mode of replacement is caused by areas of slightly differing chemical constitution in the host mineral I consider unproven and improbable. There seems to be no necessity for calling in such complications. In the case of the tennantite-stromeyerite intergrowth, described above, it has been suggested that the forms shown are caused by an intermediate stage of chalcopyrite in tennantite, the former replaced later by stromeyerite. It is true that there are some areas of chalcopyrite replacing tennantite in these specimens, but they are subordinate and utterly fail to simulate the form of the perfect pseudo-eutectic areas of stromeyerite.

The pseudo-eutectic replacements are strictly replacements by equal volume, necessitating entire removal of arsenic in the case specially described and the addition of much copper and silver. It certainly seems difficult to construe them as produced by unmixing.

It must be admitted that it is possible to conceive of subsequent replacements in a pseudo-eutectic intergrowth, just as it is possi-

ble to have the orthoclase in graphic granite replaced by kaolinite. Such a case is perhaps represented by certain specimens from the Gem channel of the Gemini Mine, Tintic.[12]

The relations of the graphic intergrowth there described as a probable replacement of galena by pearceite were not quite fully elucidated in the publication mentioned. It would now seem probable that we have here a replacement by pseudo-eutectic texture of tennantite by galena, and that the tennantite has subsequently been altered in part to pearceite. Certainly tennantite and pearceite are both present in this intergrowth and as far as known pearceite is always later than tennantite.

REPLACEMENT OF STROMEYERITE BY SILVER.

Stromeyerite, as is well known, breaks down easily into native silver. This is well shown in the same specimen described above, which illustrates the replacements of tennantite by stromeyerite. The native silver in gashes, curved veins, straight veins, and dots and dashes, replaces stromeyerite; less commonly the veins are found in tennantite or chalcopyrite. Fig. 9 illustrates the normal relation; the veinlets are curved because they generally follow the rounded outline of the large stromeyerite grains. They tend to break up into dots and dashes, and in the neighborhood of larger silver veinlets there are clouds of rounded dots which strongly recall the similar relation of chalcopyrite in sphalerite. It does not seem possible to account for these silver veins and dots by "unmixing." Frequently the silver cuts across the grain boundaries and enters from stromeyerite into tennantite or chalcopyrite.

Again we have here replacement, but controlled by grain boundaries and probably also by crystallographic directions in the stromeyerite. The silver is interpreted as of supergene origin. It replaces stromeyerite volume for volume. Copper and sulphur have been carried away, the silver remains and is added to from the solutions. There are no visible intermediate products. One

[12] Waldemar Lindgren, and G. F. Loughlin, "Geology and Ore Deposits of the Tintic Mining District, Utah," Prof. Paper 107, U. S. Geol. Survey, p. 177, 1919.

might interpret the process as an oxidation by a descending solution of silver sulphate carrying free oxygen, like this:

$$Cu_2S.\ Ag_2S. + 8O = 2Ag + 2CuSO_4.$$

However there are no traces of oxidized minerals in the ore.

The relations are illustrated by Fig. 9 and Fig. 10. The latter shows also a corner of tennantite replaced with pseudo-eutectic texture by stromeyerite and also two other areas of tennantite which have not been thus attacked.

LABORATORY OF ECONOMIC GEOLOGY.
MASS. INSTITUTE OF TECHNOLOGY.

THE ENGELS COPPER DEPOSITS, CALIFORNIA.[1]

ADOLPH KNOPF AND C. A. ANDERSON.

INTRODUCTION.

THE Engels copper deposits in Plumas County, California, in the northern part of the Sierra Nevada, present an interesting problem in ore genesis. Several writers have ascribed an igneous origin to the bornite-chalcopyrite ores of the deposits, but this conclusion later met with strong denial.

No geologic map of the area or the surrounding region has been published, except the excellent map of the Taylorsville region by Diller,[2] which was made before the mining operations at Engels were begun and does not quite extend to Engels; and most of the studies of the Engels copper deposits have dealt primarily with the microscopic features of the ore. The present writers by mapping in detail the area surrounding the mine and studying the underground workings have obtained new data on the origin of the ore deposits, and this paper presents these results. In short, the ore bodies have been localized by roof-pendants of hornfelsed andesites that extend deeply into hornblende gabbro and quartz diorite, and the ores consist chiefly of bornite and chalcopyrite with contemporaneous magnetite and ilmenite in gangues formed by the pneumatolytic alteration of hornblende gabbro, quartz diorite, hornfelsed andesite, and siliceous rock. The chief mineralizing processes were amphibolization, biotitization, magneti-

[1] Published with the permission of the Director of the U. S. Geological Survey. A detailed report on the Plumas copper belt is in preparation by the senior author as a bulletin by the U. S. Geological Survey. Dr. Anderson, prior to the examination by the senior author, had mapped the area and studied the mine in preparing a doctoral dissertation presented to the faculty of the University of California, and later he re-examined certain critical localities under the supervision of the senior author. A. K.

[2] Diller, J. S., "Geology of the Taylorsville region, California," U. S. Geol. Survey Bull. 353, 1908.

tization, ilmenitization, andesinization, and zeolitization. The maximum deposition of sulphides was in the high-temperature stage, essentially contemporaneous with the deposition of magnetite and ilmenite at about 700° C., but continued, probably in greatly diminished amount, into the final zeolitic stage.

Acknowledgments.—The writers gratefully acknowledge their indebtedness to Mr. W. I. Nelson, Superintendent of the Engels Copper Mining Company, and to Mr. A. G. Cole, Chief Engineer of the mine, for their cordial coöperation during the progress of the work. Acknowledgments are also due to Professor A. M. Bateman for aid in the examination of the ores by reflected polarized light.

PREVIOUS LITERATURE.

The earliest published account of the main ore body of the Engels mine is that by Turner and Rogers,[3] who interpreted the ore as of direct magmatic [4] origin, Turner basing his opinion on the general geological relations, and Rogers on the microscopic evidence. They described the ore minerals, chalcopyrite and bornite, as occurring in norite-diorite interstitially to the silicate minerals, which show no evidence of hydrothermal alteration. It was affirmed that no pre-plutonic rocks occur within five miles of the mine, but we now know that they are abundantly represented at the surface and occur all through the mine. This supposed absence of pre-plutonic rocks was reaffirmed by Tolman and Rogers two years later. Turner believed that the sulphides separated from the norite magma in the same manner as the feldspar and other silicates, whereas Rogers showed by microscopical study that the sulphides have replaced the feldspar and biotite of the norite, and this replacement was interpreted as having occurred during the final stage of the separation of the minerals from the norite magma.

[3] Turner, H. W., and Rogers, A. F., "A Geologic and Microscopic Study of a Magmatic Copper Sulphide Deposit in Plumas County, California," ECON. GEOL. vol. 9, pp. 359–391, 1914. The earliest unpublished account (a private report by G. H. Garrey in 1911) maintains that the deposits are a series of fissure veins in hornblende gabbro.

[4] Current synonyms: liquid-magmatic, intramagmatic, orthomagmatic.

In 1915 Read [5] made the important discovery that the norite-diorite has been cut by a later intrusion of granodiorite (the quartz diorite of the present paper), and suggested that further consideration must be given to the possibility that the norite-diorite, quartz diorite, and ore were differentiated elsewhere and brought into their present positions separately. No ore had then been found in the quartz diorite except near its contact with the more basic rock. Time's little ironies have since shown, however, that the ore extends deeper in the quartz diorite.

In a notable paper by Tolman and Rogers,[6] the view was reiterated that the sulphide minerals were added by mineralizers which attacked and replaced, during the late magmatic stage, the earlier-formed silicate minerals. They based their conclusions on the textural relationship between the sulphides and the silicates. They called attention to the fact also that the ore body is a tabular ore shoot with a nearly vertical attitude and pointed to the difficulty of explaining the formation of the ore body by gravitative adjustment due to the sinking of sulphides in the molten magma. They stated also that there is no evidence of dynamic or contact metamorphism.

Graton and McLaughlin [7] denied the pyrogenic origin of the ore, for they recognized that certain dynamic changes had taken place in the "norite," such as recrystallization of the feldspars and the local development of a schistose structure. They showed that after these dynamic changes had occurred the ore was introduced by replacement under pneumatolytic and hydrothermal conditions—a conclusion that must be regarded as impregnable.

Tolman,[8] in answer to Graton and McLaughlin, stated that the differing views on the origin of the ore were in part due to differences in the definition of terms. Tolman and Rogers' "late

[5] Read, T. T., "The Engels Mine and Mill," *Min. and Sci. Press*, vol. III, p. 167, 1915.

[6] Tolman, C. F., and Rogers, A. F., "A Study of the Magmatic Sulfid Ores," Leland Stanford Jr. Univ. Pub., No. 26, pp. 61–64, 1916.

[7] Graton, L. C., and McLaughlin, D. H., "Ore Deposition and Enrichment at Engels, California," Econ. Geol. vol. 12, pp. 1–38, 1917.

[8] Tolman, C. F., "Ore Deposition and Enrichment at Engels, California," Econ. Geol., vol. 12, p. 379, 1917.

magmatic stage" was said to correspond to Graton and McLaughlin's "pneumatolytic stage." If this were true, it would mean that the term pneumatolytic had been used by Graton and McLaughlin contrary to the usage that has grown up since Brögger first generalized the meaning of Bunsen's term pneumatolysis. As a matter of fact, the replacement process during the "late magmatic stage" postulated by Tolman and Rogers is of the category generally called magmatic resorption, or by Duparc[9] *epigenie magmatique;* whereas the alterations that are produced by gases after consolidation is complete are termed pneumatolytic. This distinction between transformations before consolidation is complete (magmatic resorption) and the transformation after magmatic consolidation has terminated (pneumatolysis) was clearly drawn in a logical analysis by Tronquoy,[10] who further distinguished between the alteration effected by the gases pervading the whole body of newly-consolidated hot rock (*"transformation pneumatolitique interne"*) and that effected by gases circulating in fissures (*"transformation pneumatolitique de fissures"*).

The emphasis that Graton and McLaughlin placed in ascribing the main metallization to a hydrothermal phase of mineralization, Tolman believed to be due to an error in interpreting the relationship of the sericite and chlorite to the ore minerals. Tolman and Rogers believed that the two minerals are later in age than the ore minerals, in which conclusion the present work completely sustains them, whereas Graton and McLaughlin thought that the sulphides were introduced mainly during and after the development of the sericite and chlorite.

Graton and McLaughlin[11] in their reply to Tolman proposed the new terms "orthotectic" and "pneumotectic" to take the place of "early magmatic" and "late magmatic." They concluded that the earliest ore at Engels was introduced during the pneumotectic stage of consolidation of the norite, but the bulk of

[9] Duparc, L., *Soc. Mineral. de France,* Bull., vol. 31, p. 60, 1908.

[10] Tronquoy, R., *Soc. Mineral. de France,* Bull., vol. 35, pp. 331–334, 1912.

[11] Graton, L. C. and McLaughlin, D. H., Further Remarks on the Ores of Engels, California," ECON. GEOL., vol. 13, pp. 81–99, 1918.

the ore was introduced during the hydrothermal stage. As, however, the ore is not genetically related to the norite and was emplaced after the consolidation of the quartz diorite, possibly after the intrusion of the quartz monzonite, it is certain that there is no pneumotectic ore at Engels.

THE PRE-PLUTONIC ROCKS.

The oldest rocks in the Engels area are a series of andesite and keratophyre lavas. Their distribution is shown in Figure 1. They are of the highest importance to an understanding of the origin of the ore deposits. They are best exposed on the high ridge south of the mine, and are here least affected by contact metamorphism. The andesites carry numerous phenocrysts of plagioclase (andesine-labradorite) in a grayish black groundmass; in places they are amygdaloidal. Representative of the keratophyres is a bluish-gray flowbanded aphanite carrying inconspicuous phenocrysts of albite. As a whole there is a considerable variety in the andesites, for they range from basaltic andesites of intersertal texture to more salic kinds.

Near the mine and throughout its workings the volcanic rocks have been drastically altered by contact metamorphism. The feldspar phenocrysts have become blurred and obscure, and the amygdules are often the only megascopic clue to the original nature of the rocks. Under the microscope the obliteration of the phenocrysts is seen to be chiefly due to recrystallization to mosaics of plagioclase of the same composition and to the concomitant growth in some of them of a ferromagnesian mineral (pyroxene, hornblende, or biotite), magnetite, and quartz. Such recrystallization of plagioclase into fine-grained plagioclase mosaics is well known from various localities; for example, it has been particularly well described from Harzburg, Germany.[12]

Some of the contact-altered andesites have become biotite-hypersthene hornfels. The biotite is notably spongiform; the

[12] Erdmannsdörffer, O. H., "Die Devonischen Eruptivgesteinen und Tuffe bei Harzburg und ihre Umwandlung im Kontakthof des Brockenmassivs," Jahrb. königl. preuss. geol. Landesanstalt, 1904, vol. 25, pp. 21, 66, 1907.

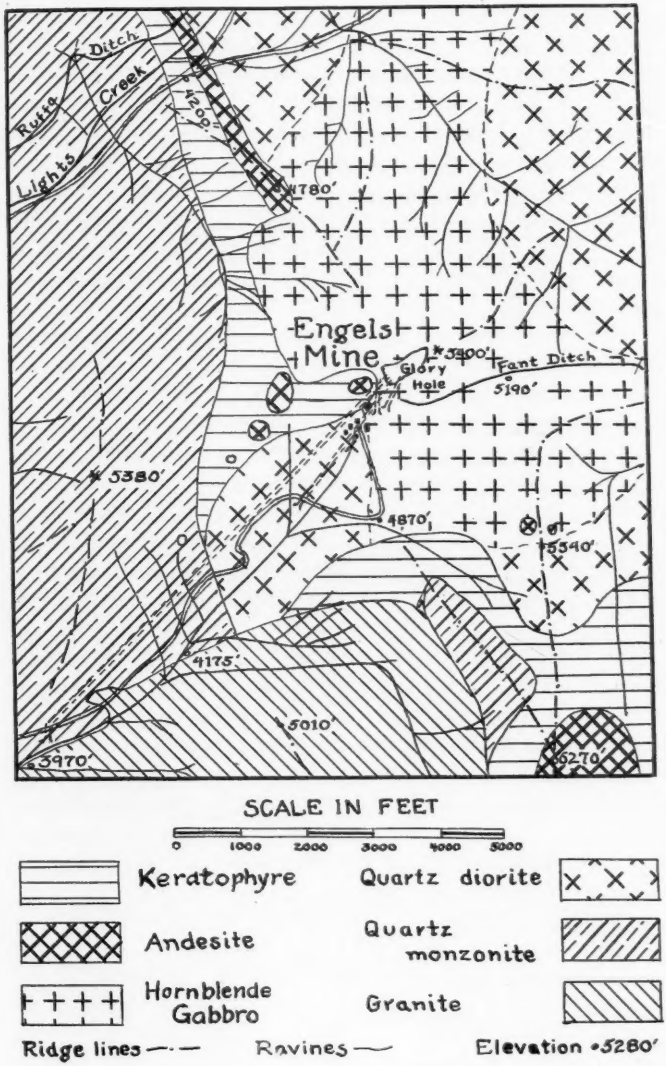

FIGURE 1. Geologic map of the area surrounding the Engels mine.

hypersthene occurs in poikilitic and round, drop-like forms; and the general matrix consists of polyhedral andesine and minor quartz. Magnetite is relatively abundant, ranging from perfect spheres to sharply euhedral crystals. It will be recalled that Harker [13] found that such rounded magnetite is common in the highest grade of contact metamorphism of basic lavas. The plagioclase in some of the hornfelses shows inverse zoning, the periphery (An_{12}) being slightly more calcic than the core, and this feature is not shown by any other rocks of the mine.

Some of the keratophyres have become snow-white as a result of metamorphism.

Some intercalated tuff beds, or beds containing admixed non-volcanic sedimentary material, occur with the lava sheets; on metamorphism they have become garnetiferous and are also more quartzose than the prevailing andesite hornfelses.

The age of this volcanic series must remain indeterminate until fossils are found in the associated tuffs. Just south of the area, Diller has mapped the nearest belt of andesites as Reeve meta-andesite, of Carboniferous age. But, inasmuch as andesites occur in this region in five different formations, ranging in age from Carboniferous to Jurassic, it does not help us much in our present difficulty.

The andesites in general are massive but some are roughly foliated, and the finer aphyric varieties as a result of contact metamorphism have become mildly foliated, fine-grained black biotitic schists. These hornfelsed andesites, where occurring in the mine, are known as metamorphic rocks, an appropriate name, and the name is also given to the altered diorite that has been transformed by the ore-forming solutions to a black fine-grained rock, much of which is megascopically (and even microscopically) indistinguishable from the hornfelsed andesites.

In addition to the general hornfelsing of the andesites, which is essentially a thermal effect, they have been locally altered in a most remarkable way. The resultant rocks were called in the field hornblendized andesites, because large hornblendes have de-

[13] Harker, A., "The Tertiary Igneous Rocks of Skye," Geol. Survey United Kingdom, Memoir, p. 52, 1904.

veloped all through them. Concurrently coarse plagioclase was formed, and the extreme result of this process was to produce rocks that resemble gabbro and hornblendite. Such powerfully hornblendized andesites occur just west of the glory hole and also along its east border, and doubtless they occur in the mine workings, where, in default of the perfect exposures that are seen on the surface showing the transitions, their origin would remain unsuspected. This alteration of the andesites can be regarded as the basic analogue of granitization.

Hornblende Gabbro.—The andesites and keratophyres were invaded by a series of plutonic rocks, the oldest of which is a hornblende gabbro. This gabbro is of great interest, inasmuch as it is one of the principal rocks in the mine and has generally been considered to be the ore-bringer. It is variable in grain size, and locally is banded, the banding being due to the alternation of hornblende-rich layers two inches thick with irregularly defined plagioclase layers 3/8 inch thick. Near some contacts the gabbro develops local facies of hornblendite.

The feldspar in the gabbro from the area surrounding the mine is the highly calcic plagioclase bytownite, and this was found true of the most unaltered gabbro obtained within the mine (from the seventh level at raise 791). This rock is brilliantly fresh, far fresher than the specimens with which the geologist ordinarily deals in the course of areal work, and the feldspars, which are glassy, prove to be bytownite, An_{80} to An_{85} (optically negative, $\beta = 1.572$). Hornblende is the chief dark mineral, ranging from 30 to 50 per cent. or more; it is a deeply pleochroic brown variety, contrasting strongly in this respect with the pale amphibole that invariably accompanies the copper mineralization. Hypersthene is in general a minor or negligible constituent, and occurs mainly within the hornblende as relicts of incomplete magmatic resorption. Augite also occurs as a subordinate component. In some of the finer-grained (millimeter-grained) facies of gabbro occurring in the mine the hypersthene or augite, or both, occur in amount equal to the hornblende. As a name for the rock mass the term norite, which has been used by other writers,

seems inappropriate; the rock is essentially a hornblende-bytownite gabbro. The bytownite is distinctly idiomorphic and the dark minerals are interstitial. Consequently if there had been some movement of the magma during the course of consolidation, causing a certain amount of filter-pressing, the resultant product would be somewhat richer in hornblende and the feldspar more sodic. This appears to be confirmed by the fact that certain melanocratic hornblende gabbros, such as that at the northeast end of the ore on Shaft level, and that in the footwall near the southwest end of the main ore body on the 7th level, contain more sodic plagioclase (labradorite), which shows a very remarkable mottling in polarized light. The plagioclase of the latter gabbro shows clearly that the mottling is due to embayment and corrosion of the cores of feldspars, which are An_{54}, by more sodic plagioclase, An_{28}. Such replacement, it will be conceded, is probably a " late magmatic " reaction, a well-known result of the working of the reaction principle. The most extreme mottling found is that seen in the hornblende gabbro of Adit 4, in which the bytownite (An_{82}) has been replaced by plagioclase of the composition An_{50}. In places the gabbro contains hornblendic blebs in which there is a little disseminated chalcopyrite, and it is by no means easy to tell whether these blebs are the results of liquid-magmatic segregation or of postmagmatic hornblendization. Some chalcopyrite was introduced during hornblendization into the hornblendized andesite roof-pendants previously described. These two items of evidence indicate that the gabbro magma contained some copper sulphide, but the amount was insufficient to produce a notable metallization, which was of much later origin.

Quartz Diorite.—The next younger intrusion was quartz diorite. A notable feature in connection with this intrusion is the extensive contact breccias it forms with the andesites and other pre-plutonic rocks. They are particularly well exposed on the 10th level and lower workings. The quartz diorite itself has been affected and rendered inhomogeneous, and moreover there has been more or less infiltration of quartz dioritic material into

the contact rocks. Some of these intrusion-contact breccias have become mineralized, and constitute valuable ore.

The quartz diorite consists of plagioclase (sharply zoned, ranging from An_{55} to An_{45}, invariably in the normal order with the most sodic zone outermost), hornblende and biotite in equal quantities, quartz, averaging 10 per cent., and minor orthoclase. The orthoclase is in general negligible and is insufficient to qualify the rock as a granodiorite. Magnetite, apatite, and also zircon, a mineral that does not occur in the gabbro, are accessories.

Near contacts the quartz diorite becomes slightly more basic; the dark minerals increase in amount and a little hypersthene may occur in addition to the usual hornblende and biotite, the quartz diminishes, and the plagioclase becomes slightly more calcic. The quartz diorite occurs in several slightly differing facies throughout the mine, so that it might at first sight be thought that there are a number of different intrusions. The coarse white quartz diorite exposed in the lowermost workings differs perceptibly in appearance from the quartz diorite seen on the surface and the Shaft level, but the transition between the two is perfectly shown in the main haulage way south of Sta. 1040.

The quartz diorite at Engels is approximately of the same composition as that making up the major batholithic masses in this part of the Sierra Nevada. Although termed granodiorite by Diller,[14] the prevailing rock was recognized by him to be quartz diorite.

Quartz Monzonite and Associated Dikes.—A fine-grained gray plutonic constitutes the next member in the plutonic sequence. It is important because the bornite-chalcopyrite veins and stockworks of the Superior mine occur in it. It is composed of oligoclase, orthoclase, quartz, and hornblende. It shows widespread tourmalinization and its hornblende has been largely altered to flaky biotite. It has graphophyric ("granophyric") and aplitic facies. Locally it is called the "Superior granodiorite," but will here be provisionally termed quartz monzonite;

[14] Diller, J. S., "Geology of the Taylorsville Region, California," U. S. Geol. Survey, Bull. 353, p. 89, 1908.

it differs much, however, from the normal granodiorites and quartz monzonites of the Sierra Nevada.

Of particular genetic interest are the dikes that cut the quartz monzonite. They comprise albitite, aplite, quartz diorite porphyry, lamprophyre (malchite), and olivine basalt. The time relation of the albitite is unknown, but the diorite porphyry is younger than the aplite, being drastically chilled against it, and the lamprophyres cut the porphyry. The copper lodes are later than the lamprophyre, and this fact is of great interest, as the mineralization at the Superior mine is in many respects like that at the Engels mine. It demonstrates that a high-temperature mineralization, indeed one of very high temperature origin, can originate long after the consolidation of the plutonic rock to which genetically it appears to belong.

Some lodes of solid magnetite also occur in the quartz monzonite, thus showing a moderate diversity of mineralization.

The olivine basalt, which is known only from a diamond drill core, is a black, fine-grained rock, to the eye exactly like the lamprophyres. It is undoubtedly related to the Tertiary basalt flows that are common in this part of the Sierra Nevada, and is therefore younger than the ore.

Granite.—The youngest plutonic rock is a coarse white granite, having an exposed area of one square mile. Sodic plagioclase (albite-oligoclase) predominates over the orthoclase, and the biotite content is very low, being only 3 per cent. by volume. Aplite cuts the granite, and a post-aplite deposit of molybdenite and pyrite occurs in the granite. Molybdenite is not known to occur in either the Engels or the Superior mine.

In summary, it appears that the plutonic rocks were intruded in the normal order of increasing silicity, and are beyond doubt the results of one major sequence, at or near the end of Jurassic time.

THE ORE BODIES.

The ore bodies of the Engels mine occur in gabbro and quartz diorite at the contacts of these intrusive masses with roof-pendants of pre-plutonic rocks. Ore occurs not only in the gabbro

and its several facies but also in the quartz diorite that is intrusive into the gabbro, and it occurs in the adjacent hornfelsed preplutonic rocks, which are mainly andesites, but include also light-colored salic rocks and quartzose hornfels. Consequently the ore differs enormously in appearance according to nature of the enclosing rocks, ranging from coarse black hornblendic rock to pale fine-grained quartz-microcline rock. Chalcopyrite, bornite, magnetite, and ilmenite are the chief metallic minerals and occur in all the varieties of ore. Chalcocite is a rare constituent, but occurs as deep as the 11th level. Some sooty chalcocite occurs on the upper levels in rock that shows acid attack, but below the Shaft level it occurs in fresh rock, dry, tight, and remote from fractures. The lattice structure that Graton and McLaughlin [15] found to occur in the chalcocite has been demonstrated by Schneiderhöhn [16] to be the result of the inversion of isometric chalcocite into orthorhombic chalcocite and therefore to prove its hypogene origin.

Pyrite is extremely rare; some authors indeed have said that it is entirely absent. Its rarity in the ores would seem to preclude the possibility that any notable amount of supergene enrichment affected the ore bodies. Biotitization is the most conspicuous form of alteration that accompanied the introduction of the ores.

The ore bodies were localized by what are in general weak shear zones, which themselves were determined by the presence of roof-pendants, or blocks detached from the main roof-pendant. In some places the evidence suggests that a salient jutting from the main mass of the roof-pendant out into the gabbro determined the position of the controlling shear zone.

There are at least four ore bodies: 1, the Main ore body, which has yielded the bulk of the ore and appears to be the one to which most of the previous published descriptions pertain; 2, the "02" ore body, in which the ore persists deepest; 3, the "08," occur-

[15] *Op cit.* p. 21.

[16] Schneiderhöhn, H., "Paramorphosen von rhombischen Kupferglanz nach regulärem Cu_2S in den sulfidischen Erzen der Tsumeb-Mine und ihre Bedeutung als geologisches Thermometer," *Senkenbergiana*, Bd. 2, pp. 1–15, 1920.

ring 300 feet in the hanging wall of the Main ore body; and 4, the ore body represented by the A-stope on the Shaft level. The positions of the ore bodies relative to one another on the 7th level is shown in Fig. 2.

FIG. 2. Plan of Engels ore bodies (shown in full lines) on the 7th level. The position of the "02" ore body on the 13th level is shown by dotted lines. A-stope ore body is projected down on the 7th level, as ore did not extend down to that level.

Main Ore Body.—The Main ore body attained a maximum length of 800 feet on the 7th level and ranged from 30 to 100 feet wide. It splits near the 7th level into two prongs, which are called the North and South ore bodies respectively, and these prongs extend several hundred feet deeper. The main ore body strikes N. 56° E., dips 80° N., and pitches 60° eastward. On the upper levels, notably on the Shaft level, the ore body is partly in the gabbro, partly in hornfels, and partly in quartz diorite. In depth the eastward pitch carries it more and more into the gabbro.

Ore from the northwest end of the ore body on the Shaft level consists of metallized hornfelses of various kinds. Some of these rocks are so obviously siliceous that their salic character was apparent underground. Microscopically they show the typical hornfels texture and consist of biotite, hypersthene, plagioclase, and magnetite. Orthoclase occurs commonly in large areas, replacing

the plagioclase in marvelous fashion—an alteration, as will presently be shown, that is very typical of the ore in the 02 ore body also. Where copper sulphides are present pale fibrous amphibole formed at the expense of the pyroxene is likely to occur, and in places epidote also occurs.

Some high-grade ore from the North ore body, 9th level, will be described in detail. The ore body is here in the hornblende gabbro, which contains little or no biotite, whereas biotite ($\gamma = 1.62$) in distinctly foliated arrangement is common in the ore body, here 30 feet wide. To the eye the ore contains bornite, chalcopyrite, and magnetite in a gangue of feldspar and biotite. Under the microscope the feldspar is found to be andesine (An_{44}) in polyhedral grains, in places fractured and showing strain shadows; the biotite, which has a distinct red pleochroism, is more or less bent and twisted. The bornite and chalcopyrite have replaced both the feldspar and the biotite, but have developed mainly between the plagioclase grains by centripetal replacement of the plagioclase. Some chalcocite occurs chiefly as rims around the bornite and chalcopyrite. Apatite is abnormally abundant, and was evidently introduced during the mineralization. Magnetite and ilmenite are abundant. Siderite is common; it was brought in later than the bornite and chalcopyrite, for in places it faithfully surrounds them as rims. Chlorite, in minor amount, occurs as an alteration product of biotite. Some occurs within the sulphides and has the appearance of having replaced the sulphides, but as it shows the same kinking as does the biotite, it is clearly biotite that became surrounded by sulphide and was later altered to chlorite.

Under reflected polarized light the magnetite, ilmenite, chalcopyrite, and bornite, show "mutual boundaries," indicating that these minerals were deposited essentially contemporaneously. In places the magnetite and ilmenite are slightly older than the sulphides. The two iron-ore minerals are readily distinguishable in polarized light, the magnetite being isotropic and the ilmenite being anisotropic and showing polysynthetic twinning lamellae. Under high-power oil-immersion lens the magnetite shows few or

no exsolved lamellae of ilmenite. The ilmenite shows minute discs or lamellae of hematite that within each grain of ilmenite are arranged as dashed lines in single orientation. These hematite lamellae were first noticed by Graton and McLaughlin.[17] They are now interpreted as the results of the breakup of an originally homogeneous solution of hematite in ilmenite. The relations of the ilmenite and magnetite allow us, as the result of the important work by Ramdohr [18] and Lindley,[19] to determine the temperature of ore deposition at Engels.

Between 600° and 700° magnetite, as shown by the experimental homogenization of unmixed solid solutions of magnetite and ilmenite by Ramdohr, is capable of holding considerable ilmenite in solid solution; on slow cooling this ilmenite separates out as narrow lamellae parallel to the octahedral faces of the magnetite. Inasmuch as the magnetite and ilmenite were deposited contemporaneously at Engels and the magnetite shows no exsolved lamellae of ilmenite, it follows that the temperature of deposition was below that at which magnetite-ilmenite solid solutions begin to unmix, *i.e.* between 600° and 700°. The ilmenite-hematite solid solution, which according to Ramdohr appears to unmix with more difficulty than the magnetite-ilmenite solid solution, has in fact unmixed, indicating that the rate of cooling in the Engels ores was slow enough for the magnetite-ilmenite solid solution to unmix, had it existed at Engels, and therefore that the homogeneity of the magnetite is not due to quenching. The ilmenite gives some indication of having unmixed in two generations, the hematite lamellae of the second generation being practically at the limit of visibility. This occurrence of exsolved hematite in two generations would indicate that the temperatures of deposition of the ilmenite had been above 675°.[20] Thus the

[17] ECON. GEOL., vol. 12, p. 11, 1917.

[18] Ramdohr, P., "Beobachtungen an Magnetit, Ilmenit, Eisenglanz und Ueberlegungen ueber das System FeO, Fe_2O_3, TiO_2," *Neues Jahrb. Min.*, Beil. Bd. 54A, pp. 320–379, 1926.

[19] Lindley, H. W., "Mikrographie der Eisenerzmineralien oberhessischer Basalte." *Neues Jahrb. Min.*, Beil. Bd. 53A, pp. 323–360, 1925.

[20] Ramdohr, P., *op. cit.* p. 375.

upper and lower temperature limits are indicated, and point to a temperature of about 700°.

The ore in places contains large prisms of amphibole one to two inches long, embedded in random orientation in the chalcopyrite. Their optical properties (feeble pleochroism; $\gamma = 1.66$ and $\alpha = 1.635$) suggest a variety intermediate between actinolite and cummingtonite, but partial chemical analysis indicates an actinolite high in ferrous iron. The walls of the ore body are assay walls, and both foot and hanging wall rocks are gabbros rich in hornblende—rocks that look fresh to the eye. They carry a little bornite and chalcopyrite in minute grains. Under the microscope the pyrogenic hornblende is found to have been largely altered to fibrous pale-green amphibole (actinolite). Biotite, so prominent in the central portion of the ore body, occurs in minor amounts only, and has formed after and probably at the expense of the actinolite. Chlorite, epidote, calcite, and sericite occur but are unimportant.

The features described for the North ore body are typical of the mine as a whole. Any ore or rock containing sulphides was invariably found to show more or less actinolite developed at the expense of the hornblende, or of the hypersthene, or augite, whether of pyrogenic or contact-metamorphic origin. Ilmenite is surprisingly abundant, probably as abundant as the magnetite. Biotitization not only of the ferromagnesian minerals, but of the plagioclase as well, is common; recrystallization of the large plagioclase feldspars into fine-grained polygonal aggregates is general, and titanite and apatite have formed during the metasomatic activity.

"02" *Ore Body*.—The "02" ore body is a vertical pipe of extremely irregular cross-section. Its major axis on the upper levels is parallel to that of the Main ore body, but on the 13th level it has turned at right angles, as shown in Fig. 2. The chief rock in which the ore occurs is quartz diorite, but pre-plutonic rocks, especially "siliceous rock" are invariably present. The "siliceous rock" in places resembles an aplite, being composed mainly of microcline and quartz, but that it is in reality highly

metamorphosed felsite and is pre-plutonic is proved by the following features: locally it shows pyroclastic structure, it is cut by granitic dikelets, and at the contact with it the quartz diorite invariably develops porphyritic feldspars.

The ore varies greatly in appearance according as bornite, chalcopyrite, and magnetite are disseminated through the hornfelsed felsite, or through the quartz diorite charged full of inclusions of dark biotite hornfelses, or through the quartz diorite. It is obvious that the metallized quartz diorite is darker than the normal quartz diorite, this darkening being due chiefly to biotitization. A common variety of ore (from the 11th level) is a fine-grained biotite-feldspar aggregate carrying bornite and chalcopyrite; it is luster-mottled owing to the presence of feldspar (orthoclase) 1 to 2 cm. in diameter. Radial stilbite is fairly abundant; rarely there occur vugs that are lined with stilbite. According to those intimately familiar with the ore bodies the presence of the stilbite, which is surprisingly abundant in the 02 ore body and somewhat less abundant in the other ore bodies, is without significance as regards the copper contents of the ore bodies.

Microscopically the ore just described is seen to contain also the metallic minerals magnetite and chalcocite. The plagioclase proves to be andesine, largely replaced by orthoclase in such fashion that rounded grains of andesine are distributed through large patches of orthoclase. It is this replacement of the plagioclase that has produced the conspicuous luster-mottling. Other minerals present are quartz and metasomatic titanite, siderite, and zeolite. The biotite in part is bent, the andesine shows some microfaulting, and the metallic minerals clearly have replaced both biotite and plagioclase. In spite of the abundance of zeolite and siderite the biotite is quite unaltered, a surprising feature. The siderite has developed in part at the expense of the magnetite, but mainly at the expense of the feldspar. The chalcocite occurs as rims around the bornite and partly as replacement of the siderite, especially along the cleavage of the siderite. No relics of igneous fabric occur in the ore, evidently because of the complex series of replacements that have occurred, beginning

with biotitization and ending with zeolitization. Ore extends, so far as now known, deeper in the 02 ore body than in any of the other ore bodies. It is now being mined on the 13th level, about 1,300 feet in vertical depth below the outcrop.

Similar ore has recently been cut by diamond drilling 500 feet below the 13th level. This, the deepest ore yet found, is a thoroughly fresh-looking granitic rock carrying disseminated chalcopyrite; it resembles the ore from the 11th level. It consists of biotite, feldspar, in large part poikilitic, and quartz, and a little visible titanite. Under the microscope it is found to consist of very abundant biotite, in part at least replacing hornblende and feldspar; hornblende, more or less poikilitic; orthoclase in large areas; plagioclase, the large pyrogenic individuals of which are partly transformed to small-grained plagioclase mosaics; quartz; abundant magnetite; chalcopyrite; and relatively abundant titanite and some apatite, both of replacement origin. The ore is a biotitized orthoclasized quartz diorite which has probably been hornblendized and into which magnetite and chalcopyrite have been introduced. It must be emphasized that the metasomatic alterations by which the quartz diorite was transformed to ore are essentially like those by which the hornblende gabbro was altered, namely, biotitization, recrystallization of the large pyrogenic plagioclase feldspars to fine-grained mosaics of andesine-labradorite, and the introduction of magnetite, chalcopyrite, bornite, titanite, and apatite.

Other Ore Bodies.—The "08" ore body is an elliptical pipe pitching eastward. It is in hornfels on the Shaft level, but passes in depth into the quartz diorite, as seen on the 6th level, and into the hornblende gabbro below this level. The most highly foliated ore seen in the mine occurs in this ore body, on the 6th level. The ore minerals are in a compact schistose biotitic gangue, the structure being of the kind peculiar to fault shear zones. The original rock was quartz diorite, which has been heavily biotitized, magnetitized, and the labradorite recrystallized into fine-grained mosaics; chalcopyrite and bornite are the ore minerals. In short, the mineralization is the normal type for the mine.

The A-stope ore body did not yield commercial ore on the 7th level; hence its projected position on the seventh level as shown in Fig. 2 is indicated by dotted lines. It is situated in the quartz diorite several hundred feet from the contact of the quartz diorite and the hornblende gabbro. Interestingly enough, some roof-pendant material occurs in the ore body here also.

SUMMARY AND CONCLUSIONS.

The ores of the Engels mine consist essentially of bornite and chalcopyrite, with much contemporaneous magnetite and ilmenite, in gangues of pneumatolytically altered rocks of highly diverse origins. The ore bodies occur in hornblende gabbro and in the younger quartz diorite which intrudes the gabbro; and they extend also into the pre-plutonic rocks invaded by the gabbro and the quartz diorite. The pre-plutonic rocks consist of andesites and salic lavas which have been profoundly altered by contact metamorphism, with the result that the andesites were altered to biotite-hypersthene hornfelses and allied types. These hornfelses persist downward to the greatest depth attained in the mine workings as roof-pendants and in part as septa between the gabbro and the quartz diorite. These masses of pre-plutonic rocks were of prime importance because they served to localize the deposition of the ore in themselves and in the adjacent plutonic rocks, both the gabbro and its hornblendic facies and the quartz diorite.

The ore deposits are steeply-dipping, and the ore body that persists most deeply, known as the "02," is an irregular pipe in quartz diorite which is being worked 1,300 feet below the outcrop and in which the mineralization, as shown by diamond drilling, extends at least another 500 feet in depth.

The alterations effected during the introduction of the sulphides and oxides were exceedingly thorough and diverse; they comprise actinolitization, biotitization, and the recrystallization of the large pyrogenic plagioclase feldspars of the gabbro (bytownite, An_{80}) and of the quartz diorite (labradorite, An_{55}) into fine-grained mosaics of andesine. The deposition of the bornite and chalcopyrite lasted longer than that of the magnetite and

ilmenite, probably only to a slight extent, however, for only rarely do the sulphides occur in fissures in the oxides. The essentially contemporaneous deposition of the magnetite and ilmenite with the sulphides indicates that the conditions during the forming of the ore were much like those that prevail during the deposition of contact-metamorphic copper ores. The ore deposition at Engels, as indicated by the experimental work of Ramdohr on the unmixing phenomena of magnetite, ilmenite, and hematite, was effected at a temperature near 700° C. The ore-forming conditions were therefore pneumatolytic, if that term is used to mean the processes whereby minerals are formed by magmatic gases acting on pre-existing or already consolidated rocks. The resultant ores and rocks seem unaltered to the unaided eye and have therefore that appearance of "lack of hydrothermal alteration" so commonly cited in support of the orthomagmatic origin of certain ore deposits. Rocks in which actinolite, biotite, and plagioclase have formed metasomatically are bound to look fresh and unaltered; in fact, it is characteristic of pneumatolytically altered rocks to have that appearance. After the period of main deposition of the oxides and sulphides, lower-temperature ("hydrothermal") alteration affected the ore bodies locally. Chlorite, zeolites, including analcite, and siderite were formed.[21] The zeolites, especially stilbite, were the minerals most abundantly formed during this stage. At this time the solutions were able to carry off more than they deposited and therefore vugs were formed. Probably the hypogene chalcocite was formed at this time. In view of the abundant zeolitization it is surprising that the biotite has remained largely intact; and it is equally surprising that the magnetite has remained intact, for almost invariably during hydrothermal alteration by solutions carrying sulphur ions magnetite is converted to pyrite. This juxtaposition of minerals of high-temperature metasomatic origin with those of low-tem-

[21] The suggestion by Cissarz (Uebergangslagerstätten innerhalb der intrusivmagmatischen Abfolge," *Neues Jahrb. Min.*, Beil. Bd. 56A, p. 272, 1928) that the first appearance of chlorite among the metasomatic products should arbitrarily be considered to mark the transition from pneumatolytic to hydrothermal conditions, is as practical as any yet made.

perature origin is assuredly one of the most remarkable features of the Engels ore bodies.

The mineralization in the Engels mine is essentially like that in the veins and stockworks of the Superior mine. At both mines actinolite, biotite, magnetite, titanite, and apatite, were formed along with bornite and chalcopyrite, and stilbite marked the closing stage of mineralization. The main difference is that tourmaline is the dominant gangue mineral in the Superior veins, whereas in the Engels ore bodies it occurs only in traces. Conformably with this difference epidote is more abundant in the Superior mine. Presumably the ores of the Engels mine were deposited at somewhat higher temperatures, from solutions less highly charged with boron.

In the Superior mine the ores occur in quartz monzonite, which is younger than the quartz diorite. On account of the widespread tourmalinization of the quartz monzonite, much of it presumably deuteric, it is natural to assume that the ore-forming solutions that deposited the highly tourmaliniferous ores of the Superior mine were derived from the quartz monzonite magma. The ores, however, are younger than the lamprophyre dikes that intersect the quartz monzonite, and the lamprophyres are younger than the diorite porphyry dikes, and these in turn are younger than the aplite cutting the quartz monzonite. Consequently, a very considerable interval had elapsed between the time of consolidation of the quartz monzonite now exposed to view and the ascent of the ore-forming solutions.

The final conclusion, therefore, is that although formerly it was thought that the ores at Engels were certainly genetically related to the hornblende gabbro ("norite"), either as late magmatic products, or pneumotectically, or pneumatolytically, or hydrothermally, it is now uncertain to which, if any, of the four members of the plutonic succession at Engels the ores are genetically to be ascribed. It is established, however, that the area was a locus of active magmatic differentiation; consequently the ore-forming solutions and the successive magmas are probably to be regarded as the products of a parent magma from which all were

derived. The stage at which the ore-forming solutions were released appears to have been in the interval of time between the intrusion of the quartz monzonite and the granite. The solutions were undoubtedly gaseous, and the conditions of chemical equilibrium prevailing in them were analogous to those that occur during the deposition of contact-metamorphic copper ores.

YALE UNIVERSITY,
NEW HAVEN, CONN.
UNIVERSITY OF CALIFORNIA,
BERKELEY, CALIF.

OCCURRENCE AND RELATIONS OF ALABANDITE.[1]

D. F. HEWETT[2] AND OLAF N. ROVE.[3]

INTRODUCTION.

PRIOR to 1916, there was record of the occurrence of alabandite in only three localities in the United States and in only about twelve other localities in the entire world. Under these circumstances, it was regarded as a rare mineral and little was recorded concerning its associations and mode of origin. Since 1916, however, it has been found in five other localities in the United States and it seems very probable that it is present in small quantities in many of the late Mesozoic and Tertiary ore deposits of the Western States.

For several years, one of the authors (D. F. Hewett) has been engaged in reviewing the geologic features of American manganese deposits. The other author (Olaf N. Rove) discovered the presence of alabandite at the Higgins Mine, Bisbee, and at the Trench mine, Harshaw, Arizona. It is believed that the publication of this review of the occurrence and relations of alabandite may facilitate a larger record of its occurrence and a better understanding of its significance in mineral deposits.

OCCURRENCES IN THE UNITED STATES.

Bisbee, Arizona.—The presence of large bodies of alabandite-bearing rock in the Higgins mine was recognized by one of the authors (Olaf N. Rove) several years ago. There are reasons for suspecting that the mineral is the principal source of the manganese which forms the bodies of oxides that are widespread in this district, and that the mineral has a similar distribution.

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Geologist, U. S. Geological Survey, Washington, D. C.

[3] Geologist, Empire Zinc Co., Hanover, New Mexico.

The Higgins mine lies half a mile southwest of the town of Bisbee and about one mile west of the intrusive mass of granite porphyry which underlies Sacramento Hill. The Dividend Fault, trending northwest, passes through Sacramento Hill and in a

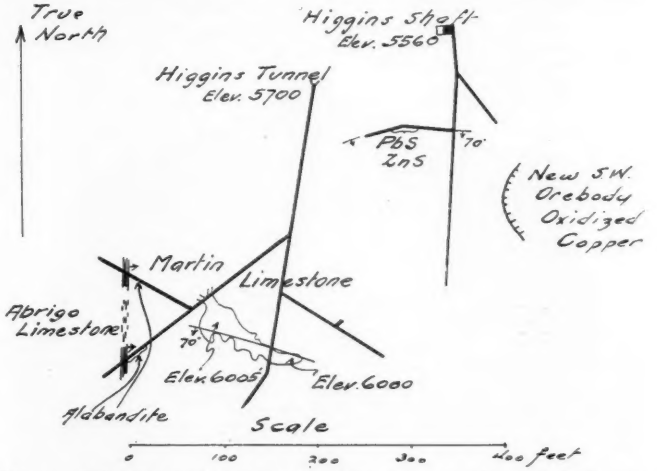

FIG. 1. Principal workings of Higgins mine showing distribution of alabandite rock.

broad way separates an area of pre-Cambrian schist on the northeast from an area of Paleozoic limestones on the southwest.[4] The workings of the Higgins Mine, near the known occurrences of alabandite are shown in Fig 1. All the workings of the Higgins tunnel are accessible; but those near the Higgins shaft from which bodies of lead and zinc sulphide were mined are not open.

The local relations of the alabandite to the bedding and structural features are shown in Fig. 2. Alabandite and a manganese carbonate replace portions of several beds of dolomite belonging to the Martin limestone near a fault which separates it from similar

[4] Ransome, F. L., The Geology and Ore Deposits of the Bisbee Quadrangle Ariz.," U. S. Geol. Survey Prof. Paper 21, p. 169, 1904. Ransome, F. L., Geologic Atlas of the United States, Bisbee Folio, No. 112, U. S. Geol. Survey, 1914. Bonillas, Y. S., Tenney, J. B., and Feuchere, L., "Geology of the Warren Mining District, Ariz.," *Trans. Amer. Inst. Mining Eng.*, vol. 55, p. 284–355, 1916.

beds of the Abrigo limestone. The beds of limestone on both sides of the fault trend northwest and dip at low angles northeast. Unlike any other recorded occurrence of the mineral, the

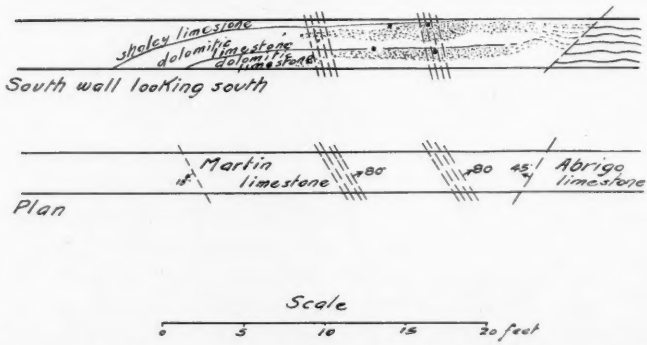

FIG. 2. Sketch of north and south walls and bottom of drift in the Higgins mine, showing local relations of the alabandite rock. Stippled areas represent alabandite rock; crosses, galena and sphalerite; solid squares, pyrite.

alabandite is present here as many minute grains disseminated through the carbonate rock, rather than as distinct coarse cleavable grains commonly 3 to 10 mm. in diameter. Fig. 3 represents a polished section of the material in which the successively darker shades indicate successively larger proportions of manganese sulphide grains. Broken fragments of this material show numerous areas that reflect light in such a way as to indicate that numerous grains have similar crystal orientation.

Three beds of dolomitic limestone are shown in the drift from the Higgins tunnel, of which two show sporadic replacement by alabandite (Fig. 2). These beds are separated by 1/8 to 1/2 inch of shale or clay gouge. The alabandite is notably concentrated in the upper half of the two lower beds, close to but not in contact with the overlying shale layers. Patches of granular pyrite seem to be localized under the shale layer but these display no clear relation to the alabandite. In addition to the impregnation by

alabandite just noted, the beds of Martin limestone are locally dolomitized. Analyses made in the laboratory of the Phelps, Dodge Co., of two beds, the shaley limestone of Fig. 2 and the underlying dolomitic limestone, show the following compositions: (1) CaO 25.8 per cent.; MgO 9.4 per cent., MnO 4.6 per cent.; (2) CaO 28.2 per cent.; MgO 16.0 per cent.; MnO 6.6 per cent.

FIG. 3. Alabandite rock, Higgins mine, Bisbee, Arizona. Manganiferous dolomite (*d*) is partially replaced by alabandite (*a*), the degree of replacement varying with darkness in color.

Sporadic dolomitization of the Escabrosa limestone may be noted over a large area south of and about 500 feet higher than the Higgins mine. The unaltered limestone is a pale gray dense rock with sparse crystalline grains. The altered rock is dark brownish gray and completely crystalline. It weathers chocolate brown. Analyses of these rocks made by J. G. Fairchild, U. S. Geological Survey, are shown below.

In addition to the disseminated grains of alabandite, the altered

rock contains sporadic patches of pyrite grains and small crystals of sphalerite and galena. Polished sections of the alabandite rock show that the texture is not homogeneous but that it is made

	Analyses.					Molecular Composition.				Total.
	CaO.	MgO.	FeO.	MnO.	Insol.	$CaCO_3$.	$MgCO_3$.	$MnCO_3$.	Insol.	
Unaltered limestone	54.37	.52	—	.13	1.35	97.05	1.08	0.21	1.35	99.69
Altered limestone . . .	35.62	14.27	—	1.15	5.24	63.58	29.84	1.86	5.24	100.52

up of angular fragments cemented by carbonate veinlets. Alabandite as well as the other sulphide grains are most abundant around the borders of these fragments. Fig. 4 is a photograph of a thin section of the border of one of these fragments adjacent

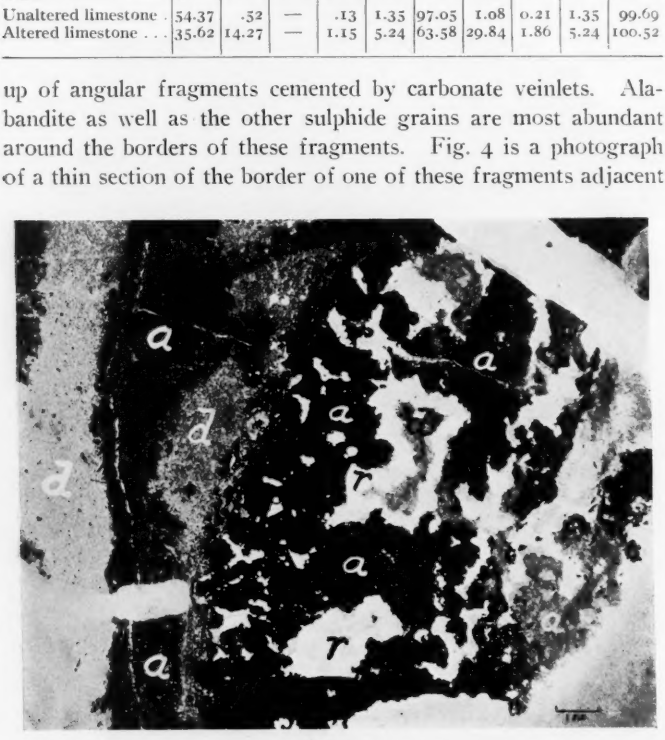

FIG. 4. Thin section of alabandite rock, Higgins mine. Manganiferous dolomite (*d*) partially replaced by alabandite (*a*). Veinlet on right shows successive deposition of alabandite, rhodochrosite (*r*) and dolomite (*d*).

to a veinlet. The left portion of the slide shows disseminated alabandite replacing the carbonate rock, whereas the right portion shows more massive alabandite in the vein with two carbonates deposited in drusey cavities. The white carbonate is probably manganiferous and the gray carbonate, dolomite.

It is interesting to speculate whether the alabandite-carbonate rock may be the source of the manganese oxide bodies that have been widely exploited in the Bisbee district.[5] The largest body found in the district thus far has yielded 20,000 tons from an open cut which lies 300 feet nearly vertically above the alabandite deposit of the Higgins mine. Although earlier reported to be psilomelane, tests of a number of specimens of the ore by one of the authors (D. F. Hewett) show that the principal mineral here is braunite in the form of myriads of minute octahedrons. This mineral replaces gently dipping beds of Escabrosa limestone on either side of a fault which trends northwest and dips steeply southwest.

It is one of the characteristic features of the manganese oxide bodies at Bisbee that they contain few voids or drusey cavities, which are common in deposits of oxides formed from carbonates and silicates. A simple calculation will show that where manganite forms at the expense of rhodochrosite, the new mineral has only 67 per cent. of the volume of the original; pyrolusite, 59 per cent.; braunite, 59 per cent. Where these minerals form at the expense of alabandite, the new minerals occupy the following percentages of the original volume: manganite, 94 per cent.; pyrolusite, 83 per cent.; braunite, 84 per cent. From these calculations, it is clear that where the oxides of manganese are derived from alabandite, the resulting deposits should show meager porosity or few voids.

In the Bisbee district the known copper ore bodies are disposed in a broad arc around Sacramento Hill, southwest of the Dividend fault. The known manganese deposits occupy an outer and upper zone with respect to that which yields copper.

Tombstone District, Arizona.—Alabandite was encountered

[5] Ransome, F. L., "Manganese Ore in Arizona; Bisbee and Tombstone Districts," U. S. Geol. Survey Bull. 710, pp. 96–119, 1920.

many years ago in the Lucky Cuss mine in the Tombstone district.[6] Manganese oxides are common in four other mines in the district but alabandite has not been observed in them. According to Ransome[7] the Lucky Cuss deposit, which has yielded most of the manganese oxide ores of the district, lies along a fault fissure between the Naco limestone (Permian and Pennsylvanian) and the Abrigo limestone (Cambrian). There are intrusions of quartz monzonite and rhyolite of late Cretaceous or Tertiary age nearby.

According to Moses and Luquer, alabandite occurs

> in the foot wall of the Lucky Cuss fissure vein in a pure white, strongly crystalline limestone. The mineral was found by following a body of oxide of manganese and lime spar ore which gradually merged into it, reaching a point where there was little else, and this afterwards gradually merging into the sulphides of iron, zinc and copper, with still a small amount of the manganese sulphide. . . . The deposit is about 100 feet above the water-level of the mine, and it is singular that it should have remained undecomposed while another adjacent deposit is thoroughly decomposed to a depth of fifty feet below the water level, the lowest point yet reached. . . . In the cleavable calcite, which is the principal associate, are found small glassy grains of pyrite and a few grains of yellowish garnet. Upon one or two specimens rhodochrosite was found, and the cleavage surface of one specimen was noticed to be coated with a mineral resembling proustite from which a silver button was obtained by cupellation.

A specimen from the Lucky Cuss mine, a part of the Roebling Mineral Collection in the U. S. National Museum, has been examined by D. F. Hewett. It contains about 85 per cent. alabandite as interlocking grains 3 to 10 mm. in diameter; 5 per cent, calcite; 5 per cent, quartz; about 1 per cent. galena as minute grains, in part in the alabandite and in part in the calcite; about 1 per cent. pyrite as minute grains largely on the borders of the alabandite grains. Another specimen in the collections of the geological department of Columbia University was kindly examined by Dr. Paul F. Kerr. It does not differ greatly from the

[6] Moses, A. J., and Luquer, L. McI., "Alabandite from Tombstone, Ariz.," *School of Mines Quarterly*, vol. 13, pp. 236–9, 1892.

[7] Ransome, F. L., "Deposits of Manganese Ore in Arizona, Tombstone District," U. S. Geol. Survey Bull. 710, pp. 113–119, 1920.

other specimen but shows the alteration of alabandite to rhodocrosite.

Harshaw District, Arizona.—Alabandite has been recognized by one of the authors (O. N. Rove) in material from the dump of the Haggin shaft of the Trench Mine, about a mile west of Harshaw in the Patagonia Mountains. According to S. E. Hollister, superintendent of the mine, the material came from a 6-foot vein on the 400-level and was mined prior to 1912. The source is no longer accessible. The Trench mine explores a simple vein in quartz diorite, considered by Schrader and Hill to be early Cretaceous or pre-Cretaceous in age. Nearby there are several flows of Tertiary andesite and rhyolite.[8]

The principal mineral associated with the alabandite is sphalerite with a distinct brown color and resinous luster. Large lumps of this mineral that appear to be nearly pure show in polished section considerable galena in small grains, alabandite and rhodochrosite. A little pyrite and calcite are present but rhodonite has not been identified. The structure of the material suggests that some of the minerals replace a breccia of the country rock, sphalerite, galena, and alabandite in the order given, while rhodochrosite was deposited in part by replacing alabandite and in part as the lastest mineral in veins and open druses.

In some specimens[9] there are aggregates of coarse grains of alabandite which cut across areas of fine grains, but microscopic examination shows that the fine grains are merely areas of coarse grains broken down into an intimate mixture of alabandite and rhodochrosite in which the carbonate replaces the sulphide. The nature of this replacement is shown in Fig. 5. In this section, grains of alabandite enveloped in a halo of pyrite appear in a matrix of rhodochrosite. The halos around some grains of sulphide are nearly complete and they are unaltered, but other halos are incomplete and only a few minute grains of alabandite remain

[8] Schrader, F. C., and Hill, J. M., "Mineral Deposits of the Santa Rita and Patagonia Mountains, Arizona," U. S. Geol. Bull. 582, pp. 253–4, 1915.

[9] The writers are indebted to M. N. Short of the U. S. Geological Survey for the examination of several polished specimens from the Trench mine and for taking several microphotographs, one of which is reproduced as Fig. 5.

in the matrix of rhodochrosite. From this kind of evidence the conclusion is reached that at an early stage the material was largely sulphides, alabandite and pyrite, but later much of the alabandite was replaced by rhodochrosite. In addition to the halos, pyrite

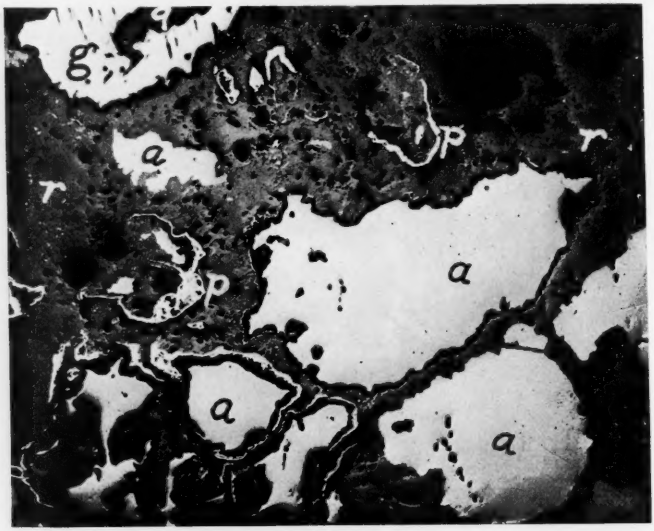

FIG. 5. Polished section of alabandite ore, Trench mine, Patagonia district, Arizona. Alabandite (*a*) enveloped in pyrite (*p*), partially replaced by rhodochrosite (*r*). Quartz (*q*); galena (*g*).

also forms minute grains and crystals in the midst of the sphalerite and alabandite.

Analyses of the coarse and fine varieties of alabandite referred to above have been made in the laboratory of the Phelps, Dodge Co. From these analyses (Table II) the probable mineral composition of the samples has been calculated.

Chiricahua Mountains.—The existence of alabandite in the Chiricahua Mountains was brought to the attention of one of the writers (D. F. H.) by W. K. Morrow, now living at Hilltop, Arizona, and the region was visited in September, 1928.

In this part of the Chiricahua Mountains, an area scarcely 10 miles in diameter contains many simple quartz and calcite veins in limestone, which have been explored for the silver content of the copper and lead sulphides. Several have been explored to a

TABLE II.

Analyses.			Calculated Mineral Composition.		
Element.	Coarse.	Fine.	Mineral.	Coarse.	Fine.
Manganese	28.2	43.0	Galena	9.8	—
Lead	8.5	0.	Chalcopyrite	1.0	1.6
Zinc	18.2	0.	Pyrite	2.0	3.7
Iron	1.2	2.2	Sphalerite	27.1	—
Copper	0.35	0.55	Alabandite	18.5	31.8
Lime	0.2	0.3	Rhodochrosite	34.6	42.0
Magnesia	0.	0.	Calcite	0.4	0.5
Sulphur	18.4	14.2	Silica, Alumina	2.4	6.1
Silica	1.8	4.2			
Alumina	0.6	1.9	Total	95.8	85.7

	Oz. per Ton	
Gold	0.01	tr.
Silver	17.2	15.1

depth of 425 feet but the total annual output of crude ore since 1906 has rarely exceeded 230 tons.

The Humboldt mine lies in SW. 1/4 sec. 15, T. 27 S., R. 31 E. (Chiricahua quadrangle) on the east side of Round Valley, 12 miles northwest of Rodeo, New Mexico. It is explored by an inclined shaft reported to be 185 feet deep and by drifts at several levels. These were largely inaccessible in 1928 on account of bad air. Near the mine, limestone beds of Pennsylvanian age (?) trend northwest and dip southwest from 20° to 30°. These beds are cut by a dike of granite porphyry 50 feet wide, which trends N. 80° E. and dips 55° N.W. There is no zone of contact minerals adjacent to the dike. The vein in which alabandite occurs lies a few feet above the hanging-wall of the dike and, like it, dips 55° N.W. The vein is of the fissure type, about 5 feet wide, largely filled with layered calcite, which is doubtless manganiferous as it weathers to shades of dark brown.

The general distribution and relations of the alabandite in the

Humboldt mine are not known. The material on the dump indicates that alabandite is the most abundant sulphide mineral, followed in order by argentiferous tetrahedrite, pyrite, chalcopyrite and galena. The sulphide minerals appear to have been localized in lenses and intimately associated with rhodonite, rhodochrosite, calcite and quartz.

From the specimens collected (see Fig. 6), the following order

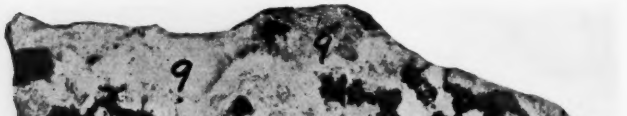

FIG. 6. Polished section of alabandite rock, Humboldt mine, Arizona. Specimen records successive deposition of quartz (*q*), rhodonite (*rh*), and alabandite (*a*).

of deposition is deduced; quartz, chalcopyrite, tetrahedrite, rhodonite, alabandite, rhodochrosite, but the study of material carefully selected underground might change the order. Most of the alabandite forms grains of irregular outline from 5 to 10 mm. in diameter. The contacts of the alabandite grains are curved rather than straight lines and when etched, many of the grains show twinning lamellae. The relations of rhodochrosite to alabandite are obscure, since none of the polished specimens show rhodochrosite.

Under the influence of weathering, the alabandite yields not

only the common oxides of manganese, but a green anhydrous carbonate of manganese. This mineral forms colloform crusts that envelop the grains of alabandite and veinlets that cut the grains, much as crusts of cerussite envelop grains of galena. The writers know of no other record of such a carbonate of manganese.

Schellbourne, Nevada.—The presence of alabandite in the Siegel mine, White Pine Co., Nevada, was noted by J. T. Pardee in 1918.[10] The Siegel mine lies on the east slope of Siegel Mountain, and it is explored by three tunnels to a maximum depth of 400 feet below the outcrop. The alabandite occurs in the St. Anthony vein which crosses the limestone, probably of Cambrian age.

According to Pardee,[11]

> As shown by the St. Anthony workings, oxidation is practically complete to a depth of 350 feet. Below this level, the vein is saturated with water and characterized by rhodochrosite and the rather uncommon mineral, alabandite, a sulphide of manganese. . . . Other constituents of the vein are quartz, calcite, pyrite and galena. Except part of the calcite, which forms secondary veinlets, all the minerals appear to be of the same generation. A banding parallel to the walls is indistinctly shown and there are fragments of partly replaced limestone in the ore. . . . Car samples representing 1,200 tons, four fifths of which came from the St. Anthony vein show an average of 37.4 per cent. of manganese, the range being from 23.2 to 45.1 per cent. Other constituents range approximately as follows: Iron 3 to 10 per cent., lead 0.5 to 4 per cent., zinc 1 to 2.5 per cent., silver 70 to 270 ounces per ton, and gold, a trace to 0.05 ounce per ton.

A specimen of ore from the St. Anthony vein, the exact source of which is not known, has been polished and examined by D. F. Hewett. It is estimated to contain 95 per cent. by weight of alabandite, 4 per cent. of rhodonite, and one per cent. of other sulphides, pyrite and galena. The rhodonite forms numerous small patches, most of which present crystals terminated toward the adjacent alabandite. Some crystals and masses of rhodonite

[10] Pardee, J. T., and Jones, E. L., Jr., "Deposits of Manganese Ore in Nevada," U. S. Geol. Survey Bull. 710, pp. 212–216, 1920.

[11] *Op. cit.*, p. 214.

are cut by veins of alabandite and it seems clear that most, if not all, of the rhodonite was deposited earlier than the alabandite. The alabandite forms interlocking grains, largely 2 to 5 mm. long and 2 mm. or less wide. Viewed as a whole, the grains present a laminated or gneissic structure, the cause of which is not known. In some localities, similar structures in galena have been attributed to pressure since deposition. The other sulphides, pyrite and galena, form grains 0.5 mm. or less in diameter, largely disposed on the contacts of alabandite and rhodonite; a few lie within the alabandite grains.

Jefferson County, Montana.[12]—Alabandite was recently recognized in material on the dump of the Helena-Jefferson mine, in the Wickes Mining district, 2 miles south of Jefferson on the Helena-Butte highway. The identity of the mineral was first suggested by J. T. Pardee.

The New York vein lies on or near the contact of quartz monzonite with aplite. The vein dips steeply north and monzonite largely forms the footwall whereas aplite forms the hanging wall. These rocks are part of the Boulder batholith, of late Cretaceous or Eocene age. The vein outcrops 800 feet north of and 300 feet higher than the Helena vein, from which argentiferous galena and blende are now being mined. The New York vein is opened by a short tunnel only a portion of which was accessible at the time of visit.

The vein has a width of several feet and is made up largely of rhodochrosite, rhodonite, and alabandite. Pyrite, sphalerite, galena, chalcopyrite, and calcite are present in small quantities. An estimate indicates that rhodochrosite and rhodonite make up 90 per cent. of the vein material, alabandite 5 per cent., and the other minerals 5 per cent. There is a little pyrolusite near the surface and fragments of vein material quickly weather black.

The relations of the alabandite to the rhodochrosite and rhodonite are shown in Fig. 7. The dark material is alabandite and the light matrix is a mixture of rhodochrosite and rhodonite. A few grains of pyrite are present in the light matrix but they are in-

[12] Prepared by F. C. Schrader.

conspicuous in the photograph. Only rhodochrosite is in contact with the alabandite and the evidence of replacement is so widespread and convincing that it is clear that considerable of the carbonate has formed at the expense of the sulphide. A thin section of the lighter matrix shows that it is an intimate mixture of rhodochrosite and rhodonite, and that the carbonate mineral has largely replaced the silicate. The silicate forms plumose ag-

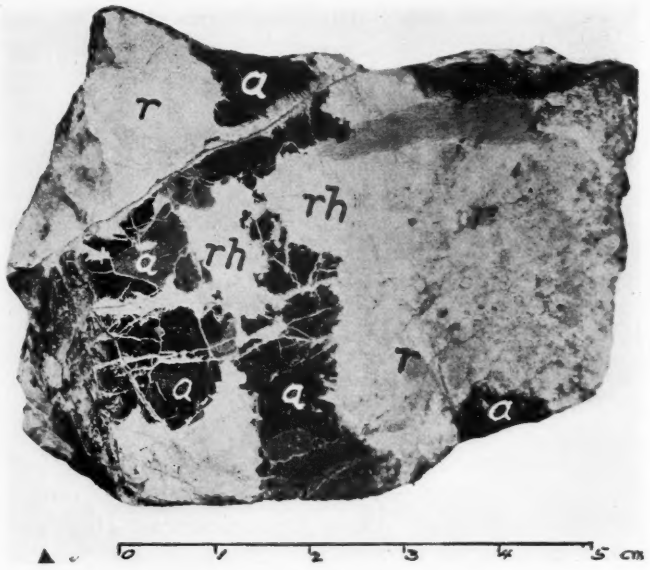

FIG. 7. Polished specimen of alabandite rock, Helena-Jefferson mine, Wickes district, Montana. Alabandite (*a*) and rhodonite (*rh*) in process of replacement by rhodochrosite (*r*).

gregates of bladed crystals which show all degrees of replacement by the carbonate. Since the silicate and sulphide are nowhere in contact, their relations are obscure, but there can be little doubt that in the material examined manganese carbonate largely replaces both the sulphide and silicate.

The chalcopyrite occurs chiefly as very small inclusions disseminated in sphalerite. Molybdenite was found in the nearby Helena vein but not in this vein. All the minerals described, sulphides, silicate and carbonates, are regarded as hypogene.

Summit County, Colorado.[13]—Considerable alabandite was found in 1887 in sinking a shaft on the Queen of the West vein at the head of the North fork of Snake River, Summit Co. The vein cuts the pre-Cambrian Idaho Springs formation, which is intruded by Montezuma granite. It contains galena, sphalerite, chalcopyrite, pyrargyrite with quartz, siderite, barite, and a little rhodochrosite. It was worked as a source of silver.

Park County, Colorado.—According to Patton,[14] alabandite is present in the Alma district, but the associated minerals and their relations are not recorded.

Mineral County, Colorado.—Emmons and Larsen,[15] noting the abundance of manganese oxides in the oxidized ores of the Amethyst mine and the meager amount of rhodochrosite, concluded that alabandite is probably present in the ore from the deep levels. The vein cuts rhyolite flows and contains galena, blende, quartz, chlorite, and barite. It was worked as a source of silver and gold.

OCCURRENCES OUTSIDE OF THE UNITED STATES.

Nagyag and Offenbanya, Transylvania.[16]—The presence of alabandite is recorded in these two districts in Hungary. These and other mining districts lie within an area 50 kilometers in diameter that present essentially similar geologic conditions. The deposits form veins in Tertiary propylitized intrusive dacite, and they are worked as sources of gold and silver. At Nagyag, the veins which contain alabandite also contain rhodochrosite, quartz, tellurides, tetrahedrite, bournonite and pyrite.

[13] Smith, W. B., *Colorado Sci. Soc. Mineral. Notes* No. 1, vol. II, p. 158, 1887. Patton, H. B., "The Montezuma Mining District, Colo.," Colorado Geol. Survey, First Ann. Rept., pp. 112–144, 1909.

[14] Patton, H. B., "Geology and Ore Deposits of the Alma District, Colo.," Colo. Geol. Survey, Bull. 3, p. 227, 1912.

[15] Emmons, W. H., and Larsen, E. S., "Geology and Ore Deposits of the Creede District, Colo.," U. S. Geol. Survey Bull. 718, p. 124, 1923.

[16] Semper, "Beiträge zur Kenntnis der Goldlagerstätten des Siebenburgischen Erzgebirge," Abh. des. K. preus. geol. Landes, No. 35, 1909.

A specimen of Nagyag ore obtained from the U. S. National Museum is made up of pyrite 2 per cent., alabandite 80 per cent., and rhodochrosite 18 per cent., deposited essentially in the order given. Although druses are lined with crystals of rhodochrosite, which rest upon layers of the same mineral, the contacts of this mineral with alabandite show clearly that the first portions of the carbonate were deposited by replacing the sulphide (Fig. 8).

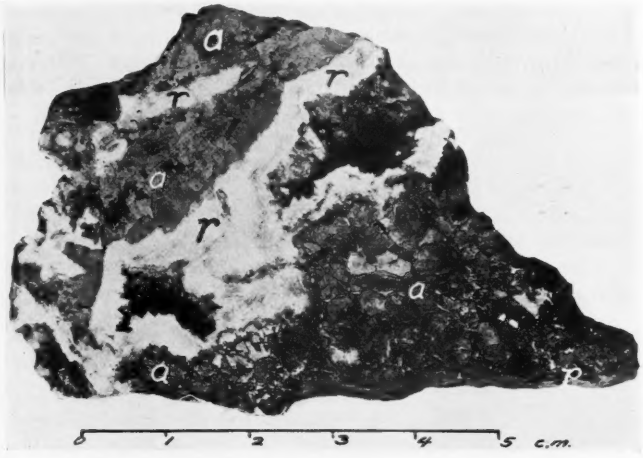

FIG. 8. Polished specimen of alabandite rock, Nagyag, Transylvania. Alabandite (*a*) in process of replacement by rhodochrosite (*r*).

Many of the grains of alabandite are enveloped by a thin film of pyrite such as shown in material from the Trench mine, Arizona (Fig. 5), and where alabandite has been replaced by rhodochrosite the films of pyrite retain the same distribution that they show in unchanged alabandite.

At Offenbanya, the veins contain free gold and tellurides, tetrahedrite, bournonite, pyrargyrite, and arsenopyrite with quartz, calcite, aragonite, and barite.

Alabandite is also reported from the Kapnik district, 125 miles

north of Nagyag, where veins in propylitic dacite have been worked as a source of silver. They contain galena, blende, chalcopyrite, pyrite, tetrahedrite, stibnite, and bournonite in a gangue of quartz, rhodochrosite, rhodonite, barite, and fluorspar.

Adervielle, France.[17]—LaCroix states:

> The Devonian shale-lime group of beds of Serre d'Azet is impregnated with manganese minerals, rhodonite, friedelite, and rhodochrosite, transformed along the outcrop into manganite. The explorations on the bed have been long opened, both along the Valley of Lauron, (Adervielle) and along the valley of the Aure (Vielle-Aure). . . . At Adervielle, rhodonite and rhodochrosite form compact rocks, ribboned like dense limestones, in the middle of which are found lamellar masses of red rhodonite mixed with quartz, of compact masses of smoky wine red friedelite, of richly saccharoidal rhodochrosite and lamellar crystals of friedelite. Interest is concentrated upon the veins of red rhodochrosite, whose crystal grains frequently attain 1 cm. These contain cavities in which the walls are covered with fine rhombs of the same mineral. More often this rhodochrosite is not pure; it is mixed with alabandite with large cubic cleavages; more rarely of hubnerite in rutile-red crystals of lamellar structure, of small hexagonal prisms, of friedelite and finally of tephroite.

Puebla, Mexico.[18]—Of this occurrence, Aguilera says:

> Manganese sulphide, alabandite accompanies the silver-lead minerals of Sierrita de Tepeyhualco, Puebla. The silicates and oxides accompany the minerals of some of the veins; the former (silicate) being found in the zone below the hydrostatic level; the latter (oxides) in the upper oxidized zone; in passing from the silicates to the oxides, the carbonate, rhodochrosite, is found in the intermediate zone. As examples, we may cite the veins of Pachuca and Real del Monte, Hidalgo, and the deposits of Tetela del Oro, Puebla.

In addition to the localities described above, alabandite is recorded from Gersdorf near Freiberg, Germany;[19] the Morococha

[17] LaCroix, A., On the minerals of the manganese deposits of the Hautes Pyrenees: *Bull. Soc. franc. de Min.*, vol. 33, pp. 351–5, 1900. (Translation by D. F. H.)

[18] Aguilera, J. S., "Geographical and Geological Distribution of the Mineral Deposits of Mexico," *Trans. Amer. Inst. Min and Met. Eng.*, 32, p. 505, 1901.

[19] Dana, "System of Mineralogy," p. 65, 1909.

district, Peru;[20] Minas Geraes, Brazil;[21] two localities in New South Wales;[22] and from Japan.[23]

GEOLOGIC CLASSIFICATION OF DEPOSITS.

Table III summarizes the minerals associated with alabandite in most of the localities where it has been found. Without doubt, the table is incomplete and probably does not adequately show the silver minerals present, since silver generally contributes most of the value to the ores in which alabandite is found. In addition to the quantitative record of the associated minerals, it should be stated that the proportion of sulphide minerals to gangue minerals is uniformly low in deposits that yield alabandite. Both from the varieties of minerals that are present, and their amount, as well as from the minerals that are absent, the conclusion is reached that the deposits belong to the class which Lindgren calls "epithermal."[24] According to Lindgren, the epithermal deposits were formed within a few thousand feet of the surface and the minerals were deposited at temperatures that probably did not exceed 200° C. Since deposits of this class are widespread in the Cordilleran region of North and South America, and the associated carbonate and silicate of manganese are recorded widely in this region, it would seem that alabandite is of common occurrence and with careful search can probably be found widely distributed if not present in large quantities.

AGE OF THE DEPOSITS.

Of the seven localities in the United States from which alabandite is recorded, an appreciable range in age is indicated, but all are relatively young, geologically speaking. According to Ransome, the ores of Bisbee were deposited in the interval be-

[20] Raimondi, A., "Minerales del Peru," p. 216, 1878. Pflucker and Rico, *Annales del Escuela Minera*, vol. 3, p. 16, 1883.

[21] Leonhard, "Top. Min.," p. 385, 1843.

[22] Liversidge, "Mineralogy of New South Wales," p. 111, 1888.

[23] Wada, "Mineralogy of Japan," Tokyo, 1904.

[24] Lindgren, W., "Mineral Deposits," pp. 576–598, 1928.

TABLE III.

LIST OF MINERALS REPORTED WITH ALABANDITE.

	Bisbee, Arizona.	Tombstone, Arizona.	Harshaw, Arizona.	Chiricahua Mts., Arizona.	Schellbourne, Nevada.	Summit County, Colorado.	Wickes, Montana.	Pueblo, Mexico.	Nagyag, Transylvania.	Offenbanya, Transylvania.	Karacl, Transylvania.	Kapnik, Transylvania.	Adervielle, France.
Sulphides													
Alabandite	×	×	×	×	×	×	×	×	×	×	×	×	×
Sphalerite	×	×	×	×	×	×	×	×	×	×	×	×	
Galena	×	×	×	×	×	×	×		×				
Pyrite	×	×						×	×		×		
Chalcopyrite	×	×											
Tetrahedrite													
Pyrargyrite													
Bournonite										×			
Tellurides													
Gangue minerals													
Quartz	×	×	×	×	×	×	×		×	×	×	×	×
Calcite	×	×									×		
Dolomite	×					×				×			
Siderite						×			×		×	×	×
Rhodochrosite	×	×	×	×	×	×	×	×	×				
Rhodonite													
Friedelite													
Tephroite													
Garnet		×				×							
Barite													
Hubnerite													×

tween Pennsylvanian and Comanche (lower Cretaceous) time, whereas those of Tombstone were deposited in the interval between Comanche and Tertiary time. According to Schrader and Hill, the deposits in the Harshaw district occur in late Mesozoic intrusive rocks and are probably Cretaceous in age. Of the silver deposits of the Chiricahua Mountains, Arizona, it can only be stated with assurance that they are post-Pennsylvanian; probably they are late Cretaceous. The deposits of Colorado and Montana are probably late Cretaceous or early Tertiary. In Europe, the deposits in Transylvania, Hungary, occur in volcanic rocks of Tertiary age. Of the remaining deposits which contain alabandite in France, Peru, Brazil, Mexico, New South Wales, and Japan, it has not been possible to ascertain an assignment of age.

PARAGENETIC RELATIONS.

Interpretations of parageneses based upon the examination of a few specimens, the exact source and relations of which are obscure, involve uncertainties and are generally susceptible of considerable revision. In this instance, however, they seem worthy of record. There seems to be no conclusion concerning the relations of the several sulphide minerals that is worthy of emphasis. Whatever may be the variations in order of deposition shown, all the sulphide minerals seem to have been deposited in one general epoch. The relations of alabandite to the carbonate and silicate of manganese from several sources seem to be constant. The silicate, rhodonite, is assuredly the earliest manganese mineral in material from Schellbourne, Nevada, and Chiricahua Mountains, Arizona, and is either earlier than or contemporaneous with the sulphide from Wickes, Montana. Also, the carbonate, rhodochrosite, is uniformly the latest manganese mineral in each locality, and the first portion of it forms at the expense of either alabandite or rhodonite by replacement, even though in several places it is later deposited in layers or as crystals in drusey cavities. This process of replacement of alabandite by rhodochrosite has been noted by others in several localities and the conclusion is stated that it is the result of a supergene process.

From what is here recorded concerning the sources of alabandite, it is clear to the writer (D. F. H.) that the alteration is the result of a hypogene process. In this connection, the writer has observed in material collected by J. T. Pardee from the Valdemere mine, Butte, Montana, that rhodonite shows considerable replacement by rhodochrosite, and W. S. Burbank, of the U. S. Geological Survey, has noted the same process in the Camp Bird vein and Kerber Creek district, San Juan Mountains, Colorado.

The foregoing relations indicate that there is a tendency toward the successive deposition of silicate, sulphide and carbonate of manganese in a given vein, the latest mineral (carbonate) being formed in part at the expense of those which preceded it. This conclusion is interesting both for its bearing on the mode of origin of veins that contain manganese silicate, sulphide, and carbonate, and for the light that it throws on the nature of the processes which take place in epithermal veins. Whatever the conditions of deposition of manganese silicate and sulphide may be, it seems clear that the alteration of both minerals to the carbonate is accomplished by aqueous solutions since there is no evidence of change in volume and in the process about 30 per cent. of the manganese present as sulphide is removed from the space later occupied by the carbonate. Aqueous solutions seem to offer the only mechanism for removing a part of the manganese to a higher zone in the vein. In other words, the veins in which are found the mineral relations described above, were not formed by a simple process of successive deposition from solution of the minerals present, but involved early deposition followed by later attack of the early group of minerals by solutions of different character. This process resembles that recently recognized as characteristic of pegmatites where the early orthoclase is replaced by albite.[25]

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

[25] Hess, F. L., "The Natural History of the Pegmatites," *Eng. and Min. Jour.*, vol. 120, pp. 289–298, 1925. Schaller, W. T., "The Genesis of the Lithium Pegmatites," *Amer. Jour. Sci.*, (5) vol. 10, pp. 269–279, 1925.

CLASSIFICATION AND SPECIFICATIONS OF SILICEOUS SANDS.

RALPH TUCK.

THAT "familiarity breeds contempt" is probably truer of the attitude of economic geologists toward sand deposits than of other economic material. However, although the ordinary observer pays scant attention to the uses and production of sand, it is notable that during the year 1927, 197,454,269 short tons were produced, having a value of $54,291,398. The uses of sand in order of value are: building, paving, molding, glass, grinding and polishing, engine, railroad ballast, fire or furnace, filter, chemical and metallurgical, and numerous other uses.

Since there seems to be some misunderstanding on the part of many as to just what is included under the term "sand," it may be of interest to see first what the name really means, for it has been sometimes rather loosely defined. A few of the definitions are as follows:

Fox,[1] defines it as: "Material from .1 to 2. mm. in size. Size is the important factor. Many kinds of sand, but the term usually implies quartz grains only."

According to Sorsbie,[2] sand is: "The material constituting the fine-grained siliceous rocks called sandstone."

Middleton[3] says: "The term sand may be applied to small grains of any material as found in nature; it is generally confined in its use to those of quartz."

In Bulletin 3 of the National Sand and Gravel Association, we find: "Sand and gravel is the granular material which results from the natural process of weathering and erosion of rocks; usually a siliceous or calcareous rock. Sand is generally considered as that portion of the material finer than about ¼ inch, and gravel as the material coarser than that size."

[1] C. S. Fox, "Civil Engineering Geology," p. 134.
[2] R. F. Sorsbie, "Geology for Engineers," p. 112.
[3] G. A. Middleton, "Building Materials," p. 161.

Searle[4] states: "Sand is the term used to indicate small grains of silica in the form of quartz or quartzite or of the minerals of a highly siliceous character. In the broad sense it may be regarded as naturally-occurring powdered rock of an indefinite composition, produced by water, wind, and weather. It ranges in size from 1/1000 to 1/20 inch."

Twenhofel[5] gives an indirect definition as follows: "Sandstone is a rock made up of small rounded or angular grains of mineral or rock fragments which have been derived from some pre-existing rock." "Sand stones are but cemented and consolidated sands, and the following description of the latter applies to the former except for the features of cementation and consolidation."

A summary of the definitions indicates that in the majority of cases, size is the important feature, and while most of these state or intimate that the grains are siliceous, a few leave the question open. Some, like Sorsbie,[6] specify that the sand must be siliceous, but they do not state what the unconsolidated material that is of the same size but of a non-siliceous composition is to be called. Is it sand also? It might be pointed out that the term sandstone generally refers to consolidated siliceous grains, having a commonly accepted size range. The term sandstone then would imply that the term "sand" itself applies only to siliceous material.

Accepting the definition that the term "sand" applies to the physical condition of size only, and assuming that a calcareous or gypsum sand becomes consolidated, it would not be customary to call the resulting rock a sandstone, and yet in order to be consistent with the terminology, a consolidated calcareous or gypsum sand would be called that. This would seem to indicate that distinct meanings are necessary for the terms "sand" and "sandstone."

A definition of sand should contain the following features. An aggregate of unconsolidated or loosely coherent minerals or rock fragments, that range in size from 1/500 to 1/8 inch, and are a result of the weathering and erosion of rocks through the agencies of wind, water, and ice. The grains may be either ang-

[4] A. B. Searle, "British Clays, Shales and Sands," p. 254.
[5] W. H. Twenhofel, "Treatise on Sedimentation," p. 165.
[6] *Op. cit.*

ular or round, but the size of grain is the important factor. It may be composed of any material, but usually it is chiefly siliceous. Ries and Watson,[7] Teas,[8] and Wentworth[9] give very similar definitions.

In accordance with the definition we might have, and we do find; quartz, feldspar, dolomite, calcareous, gypsum, shale, magnetite, monazite, garnet, volcanic and various other sands. They may contain 100 per cent. of the mineral grains noted, or they may be a mixture of grains of different materials, sometimes contaminated with clay and silt. The most abundant and widely used sands are the siliceous ones.

Although a geologic report of a region may give in much detail the characteristics of most of the economic deposits, scant attention is usually given to the sand deposits, and this is perhaps chiefly due to the lack of knowledge of the specifications for the varied uses. In general the specifications are scattered or inconveniently located, and in addition there is some diversity of opinion regarding them, so it is rare that two users of sand agree exactly as to the requirements. A contributing factor to the confusion is the use of local sands, which may not fulfill all requirements, but are used nevertheless for reasons of economy.

An important basis of specifications is size, and much confusion is caused here by the fact that no uniform series of sieves are used, and those employed are not always carefully calibrated.

The properties upon which the uses of sand depend are: The presence or absence of clay, mineralogic composition of the sand, purity, size of grain, distributed grading, uniformity of grain size, and the angularity of the individual grains. Any attempt at classifying sands as to their uses cannot be clean cut and concise. Not only is there considerable difference of opinion regarding the specifications of an ideal sand, but one sand may be adapted to several uses. In general the presence or absence of clay, and the uniformity of grain size seem to be the most com-

[7] Ries, H., and Watson, T. L., "Engineering Geology," p. 95.
[8] Teas, L. P., Georgia Geological Survey, Bull. 37, p. 1.
[9] Wentworth, C. K., *Jour. Geol.*, vol. 30, p. 377, 1922.

mon properties that appear in the specifications, and therefore the most feasible means of classifying sands as to their uses.

An attempt has been made to construct a classification of siliceous sands, indicating the uses on the basis of their properties and also giving the specifications for different uses. It should be understood that the specifications of sands differ, and those given below are generalized and possibly in some cases idealized. They are a result of a summary and compilation from a number of sources.

Acknowledgments and thanks are due to Messrs. W. M. Weigel and C. E. Proudley, and Professors H. Ries and C. M. Nevin for their constructive criticism of this table.

CLASSIFICATION AND SPECIFICATIONS OF SILICEOUS SANDS.

A. NO CLAY PRESENT.

1. **Grains Uniform in Size.** (For the purpose of this classification the grains will be considered uniform in size, if at least 90 per cent. approach a specified size.)

Filter Sand.—As uniform in size as possible. Either round or angular grains. Free from clay and organic matter. Not more than 5 per cent. material soluble in HCl. The typical sand has at least 90 per cent. finer than 1 mm., and not more than one per cent. finer than 2 mm. Effective size[10] .25 to .50. Uniformity coefficient[11] 1.5.

Glass Sand.—Grains of a uniform size. Size range between 20 and 100 mesh. Silica at least 95 per cent. Iron from 1 per cent. to .02 per cent. depending on the type of glass. Alumina from 4 per cent. to .1 per cent. No coarse grains as they are left unfluxed. Sharp grains flux more easily than round ones, but many sands with round grains are used.

Sand Blast.—Uniform in size. Size range from 4 to 48 mesh. Prepared in different sizes. Free from clay and few cleavable grains. Rounded grains are more durable but angular ones cut faster.

[10] The "effective size" of a sand is such that 10 per cent. by weight of the sand is finer than this size, and 90 per cent. is coarser. It is expressed in millimeters.

[11] The "uniformity coefficient" is defined as the ratio of the size of grain which has 60 per cent. finer than this size, to the size which has 10 per cent. finer (the effective size). The smaller the coefficient the more uniform the sand. If exactly uniform, the coefficient would be 1.

Stone Sawyers' Sand.—Sharp and uniform in grain size. Flat grains are useless. Through 20 mesh and retained on 60 mesh.

Grinding and Polishing Sand.—Uniform in size and free from coarse grains. For polishing glass, the sand should pass through 20 mesh. Size varies depending on use.

Sand for Carborundum Manufacture.—Over 99 per cent. silica. Even grained. Sand that will pass through 150 mesh should not be used.

Potter's Sand.—Two grades: (1) fine, 28 to 100 mesh. (2) coarse. 10 to 40 mesh. Free from dust and fairly well sized. For light colored ware, the sand should be low in iron and fluxes.

2. Grains May or May Not Be Uniform in Size.

Chemical and Metallurgical Uses.—Approach glass sand in purity. Iron, aluminum, lime, magnesia and phosphorus, should be present only in traces.

Sand for Pulverizing.—Only high grade pure silica sand is used. Used for abrasives, paint filler, ground silica, etc. It is ground to varying degrees of fineness.

Traction Sand.—Preferably 95 per cent. silica. Free from material that will hold moisture. Ideal sand would pass 20 mesh and be retained on 80 mesh. Preferably angular.

Sand-Oil Roads.—The sand should be sharp, and well graded (distributed sizes).

Stucco Sand.—100 per cent. should pass through 4 mesh, and not more than 5 per cent. should pass through 100 mesh. Clean from clay and silt.

Roofing Sand.—White, dustless sand. Ranging in size from 20 to 100 mesh.

Concrete Sand.—See B 1.

3. Grains Not Uniform in Size.

Sand-Lime Brick.—At least 80 per cent. silica. Should pass through 20 mesh. Not more than 2 per cent. clay. Should be of various sizes.

Asphalt Pavements and Flooring Sands.—Free from clay and silt. Clean, sharp sand with a small percentage of voids. Between 4 and 200 mesh. Well distributed sizes. Passing through 200 mesh, not more than 5 per cent. Retained on 10 mesh, not more than 1 per cent.

Cushion Sand (*Sub-grade Sands*).—Some clay may be present. Should pass through ¼ inch screen, and at least 40 per cent. retained on 10 mesh.

Concrete Sand.—See B 1.

B. CLAY MAY OR MAY NOT BE PRESENT, AND IF PRESENT IS IN LIMITED OR SPECIFIED AMOUNTS.

1. Non-uniformity in Grain Size.

Brick Mortar Sands.—Should pass through 10 mesh and 80 per cent. should be coarser than 100 mesh, depending on thinness of joints. No organic matter present. 3 per cent. maximum amount of clay present.

Concrete Sands.—Little or no organic matter should be present. Clay not over 3 per cent. by weight. Distributed sizes important.

Passing through ¼ inch screen 95–100 per cent.
Passing through 50 mesh screen 5–30 per cent.
Passing through 100 mesh screen 0–8 per cent.

Stone Masonry Mortar Sand.—Should be clean and even grained. Maximum size ¼ inch, but size should vary depending on the thickness of the coat.

Fire or Furnace Sand.—Used with lime or fire clay binder. 97 per cent. or more silica so as to prevent fusion. Clay if of high fusion may be present as a natural binder. Distributed range in size is preferable.

Core Sand.—Generally a medium grained sand, to which may be added artificial binders that will be destroyed. May contain small amounts of clay. Not more than 3 per cent. material other than silica. Distributed sizes are the best.

Plaster Sand.—Should pass through 10 mesh and at least 80 per cent. retained on 50 mesh. Little or no organic matter. Clay up to 5 per cent. permissible. No soluble salts (no sea sands).

Railroad Ballast Sand.—90 per cent. coarser than 12 mesh. Fairly free from clay and dirt.

Sand-Lime Brick.—See A 3.

Cushion Sand.—See A 3.

C. CLAY PRESENT.

1. Non-uniform Grain Size.

Sand-Clay Roads.—70 to 90 per cent. sand. Coarse grained and angular. The rest of the material should be clay.

Sand—all pass ¼ inch screen and 45 to 60 per cent. retained on 60 mesh.
Silt—5 to 20 per cent. material passing 200 mesh.
Clay—10 to 25 per cent.

Foundry Sands.—Wide range of specifications depending on the type of casting. In general the requirements are: 2 to 20 per

cent. bond (largely clay), to furnish cohesiveness. Durability of sand depending on refractoriness of bond. Permeability variable. A good distribution of sizes. Size of grain usually depending on type of casting.

SIEVE TESTS OF A FEW CHARACTERISTIC SANDS.

No.	Thru 200	On 200	— 150	— 100	— 80	— 65	— 60	— 50	— 48	— 40	— 35	— 30	— 28	— 20	— 10	— 8	— 6
1			99	94		71			34		4						
2				100		99			87		47		5	.1			
3									100		99		99	72			
4											100		99	99	78	16	.3
5															100	99	91
6				99	98			95				50		5			
7		95		78		19					.8						
8					89		72			1							
9	28	9	22	6	13		11			5				3			
10	.8	.2	.4	.5	.6		4			80				13			
11	24	4.5	2	3	4		16			35				7			
12	8	.4	2	1.5	8		10			34				35			
13	19	1	1	1	1		10			34				32			
14	1	.1	1	1.5	5		38			48				4			
15	74	15	10														
16				97			82			15				1			
17			98	97	89		53	43		25		13		3			

1. Banding Sand, Ottawa, Ill.
2. No. 1 Sand blast sand, South River, New Jersey.
3. No. 2 Sand blast sand, Phalanx, Ohio.
4. No. 3 Sand Blast sand, New Brunswick, New Jersey.
5. No. 4 Sand blast sand, Cape May, New Jersey.
6. Engine sand, Memphis, Tenn.
7. Furnace sand.
8. Roofing sand.
9. Medium textured molding sand.
10. Coarse core sand.
11. Facing sand.
12. Fire sand.
13. Molding sand (coarse).
14. Steel sand.
15. Parting sand (usually pulverized).
16. Glass sand, Ottawa, Ill.
17. Sand for oxychloride cement.

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CORNELL UNIVERSITY,
ITHACA, N. Y.

ECONOMIC GEOLOGY AND ALLIED SCIENCES IN ANCIENT TIMES.

CORNELIO L. SAGUI.

THE scientist is always interested in the history of his science, but in the case of the economic geologist not much historical research has been made, although his science is one of the oldest and undoubtedly was the most important in ancient times, when physics, chemistry, metallurgy, and mechanics were its subsidiaries. The Greeks, indeed, used to use the term μεταλλεῦς for the worker in the mine as well as in the smelting plant, which proves the union of the different technical branches under the same denomination. The economic geologist was certainly the leader among those technicists, on account of the close relations between field work and smelting practice. Ancient writers, it is true, do not give much information on the subject, but we gather from their texts that above the miner (μεταλλεῦς), the carriers (θυλαχοφοροι), and the smelters (κἰδδανες), were the overseers (δῦλακες) and technical officers (επισταται and εργεπιστατης). The latter, although slaves,[1] were accorded certain privileges on account of their technical ability; and so well did they appreciate the advantages of liberty that they kept their science secret and transmitted it as a precious hereditary gift from father to son, as was also the custom in the mason guilds of the mediæval Comacine masters, with their mysterious and marvellous art in the building of cathedrals and castles.

We modern people have forgotten what a precious gift liberty is, and sometimes give it up as nonchalantly as though it were useless. Yet freedom is at the very base of progress, and the strange specimens of our modern humanity who

[1] Demosth. XXXVII, 4, 5.

believe it a dangerous thing should look back upon the slaves of the Greek and Roman mines and learn what the loss of liberty means.

In ancient days the writers, philosophers, historians and artists were too busy to pay much attention to the economic geologist, whose humble history as a slave and an associate of slaves was very imperfectly recorded. Nevertheless Possidonius, Diodorus, and Pliny expressed their admiration for the mining operations of their times, although their ignorance of the technique prevented their writing in detail concerning miners and their methods.

It is somewhat difficult to establish a date for the first use of metals. Perrot [2] concluded that the Greeks used gold, silver, lead, copper, and brass some fifteen centuries B.C. But near Thira, on the island of Santorini, buried under a lava flow of more than 2,000 years ago, have been found handsaws of copper and rings of the same metal.[3]

From my own investigations, I believe that the Cassandra mines were worked some twenty-five centuries before the time of Alexander the Great. Such a conclusion seems not much at variance with that of Montelius,[4] who concluded that copper was used in Italy twenty-five to thirty centuries B.C. Yet iron, which appeared long after other metals, dates back, in the opinion of Bertrand and Reinach,[5] a period of thirty-two or thirty-three centuries; also, from metallic objects found in the tombs of Warka and Mongheir and in Ur [6] in Chaldea, it is inferred that metals were in use along the Mediterranean coasts more than thirty centuries B.C.

It is, without question, a story of long ages, and economic geology and its allied sciences had time to develop extensively. But the oblivion of the Dark Ages necessitated a fresh start not many centuries ago along the same principles that were

[2] Perrot, "Hist. de l'Art."

[3] Fouque, "Santorino."

[4] Montelius, Arch. für Anthrop., 1900.

[5] Bertrand, A., and Reinach, S., "Celts dans la vallée du Po."

[6] University of Pennsylvania Museum Expedition, "Discoveries in the Ruins of Ur of the Chaldees."

undoubtedly known in antiquity. Such is the history of humanity; a lesson repeatedly learned and forgotten; never learned well, but frequently well forgotten, a condition which seems a *sine qua non* of our strange destiny.

Prospecting.—Ancient prospectors developed their science slowly, and it is impossible to establish when or where it started. We only know that commercial intercourse throughout Europe was active during the early Egyptian dynasties, since they used amber from the Baltic Sea;[7] also from remote antiquity tin was carried from Spain, Gaul, Saxony, Bohemia, Wales and the mysterious Cassiterides Islands mentioned by Herodotus, to the Mediterranean shores. The Phoenicians, the boldest navigators of those days, took their prospectors everywhere in search of metals; it is probable that they took possession of the islands of Thasos and Siphnos, and mined the copper ores of Cyprus, which contained gold. They also discovered the famous mines of Thasos, Herodotus informs us,—*μεταλλα ανευρον*; and E. Meyer surmises that Sardinia was discovered by the Phoenicians fifteen centuries B.C.; while Diodorus states that they exchanged goods for silver in Spain at about the same period.

But in Greece, Macedon, and Thrace, mining was started before the arrival of the Phoenicians; in fact, in the district of Laurium, near Athens, ruins of the Mycenian type[8] have been discovered. It is probable, also, that the Phoenicians were not the first workers at Cassandra. Their supremacy on the sea was reduced in great measure by Greek and Etrurian mariners, who were predominant in the sixth and seventh centuries B.C.[9] At about this time the mines in Etruria were working at full blast at Elba, Montecatini (Volterra), Massa Marittima, Rocca-Tederighi, Montieri, Strettoia, Fornovolasco, Bottino and elsewhere.[10]

It is thought, however, that with the exception of the

[7] Perrot, *op. cit.*

[8] Stais, "Εφημ.αρχαιολ."

[9] Mommsen, "Hist. Rom."

[10] Martha, "Art Etrusque."

Egyptians, the Phoenicians were the most ancient and skilful prospectors. Cadmus, a celebrated Phoenician, is said to have founded Thebes in Beotia, and imported the Phoenician alphabet into Greece sixteen centuries B.C., also to have discovered the gold at Mount Pangeon.[11]

Polybius, Strabo, Pliny, Plutarch, Pausanias, Herodotus, and others, state that mining districts were active in Spain, Italy, and Greece; and Pliny, a Roman and proud of his country, pretends that Italy was a very rich mining field, his love for his country being evidently greater than for the truth! But these celebrated writers did not go into details regarding this interesting industry, which no doubt appeared to them a magical science, for metallurgy was then considered a sacred calling, though no special deity protected it; only modest local deities—*genii loci*—presided over mines, geologists, and miners.

Even though the references in literature are somewhat laconic, we know that a considerable number of metals were treated, among them zinc and antimony, since at Tello (Chaldea) a fragment of a vessel of pure antimony was found,[12] and alloys of antimony, copper, and lead were used in making domestic articles, such as mirrors.[13] Roman coins frequently contained as much as 20 per cent of zinc, whereas aurichalcite seems to have been known as καδμῖα λίθος; brass also was obtained by smelting copper ores with calamine.

Tin was brought to the Mediterranean shores, writes Diodorus of Sicily, from as far as Iktis (Isle of Wight) and Wales; the tin ores nearer by were also intensively prospected and mined, so thoroughly, in fact, that modern books on mineralogy frequently do not even mention the occurrence of such ores in Tuscany. Nevertheless, I found at Mount Valerio cassiterite intimately associated with iron ores, and at Mount Rombolo, also in Tuscany, a peculiar ore which looks like clay and contains lead, tin and arsenic, is occasion-

[11] Movers, "Die Phönizier."

[12] Berthelot, "Alchimistes grecs.".

[13] P. Gaudin, *Bull. Soc. Antiq. de France.*

ally met with. Only occasionally, because the activities of the ancient workers have left only a network of empty shafts.

They really knew, those remarkable slaves of former days, how thoroughly to exhaust a mining district. At the Cantabres Mountains, near Salabe (Ribadeo), Spain, not less than four million cubic meters of material was mined, and not a speck of tin ore was left. Three long tunnels for dewatering the mines remain as witnesses of former activity, also extensive underground works. At Ablaneda (south of Salas) mining was even more intensive. Three long aqueducts, one above another, the longest about ten kilometers, were built to bring water to the ore dressing plants.

The methods used for locating ore are unknown, though Pliny writes that the presence of iron was detected by the red color, and certain colors were considered indicative of other ores. It is evident that in the mining district of Laurium the ancient geologists were quite aware that the useful ores were to be found along schist and limestone contacts, and in central Italy, at the Capanne Vecchie, Poggio Montierino, and Serra Bottini mines, the boundaries of the copper deposit were correctly delimited by shafts.

Prospecting methods (*καίνοτομια* or *καινομεταλλον*)[14] were in accordance with sound economic geologic principles. At Linares, the Hannibal shaft was driven in the country rock and the vein was reached by a cross-cut 30 meters in length at a depth of 30 meters. At that point the vein was barren, but after 40 meters of drift, minable ore was struck.[15] Our modern geologists would hardly be able to do better. At Cassandra the writer had opportunity to study quite thoroughly the evidences attesting the skill of our ancient colleagues, and it is to be regretted that their lore is not available; it would be, unquestionably, not only an archaeological curiosity but a useful addition to our present literature, inasmuch as our science is, after all, a synthesis of observations,

[14] Xenophon, "De Vect.," IV.

[15] Daubree, *Rev. Arch.*, 1881, Paris.

and those of ancient prospectors were presumably no less important than our own.

At Huelva, Spain, the ancient prospectors discovered most of the copper veins of that district, and the same may be said of many other districts. Pliny informs us that any important mining work was preceded by a careful field survey, and a sample (*segutilum*) was always taken from the deposit under investigation. This sample was washed, but the further procedure in its analysis is unknown.

At this point let me emphasize the fact that ancient geologists were perfectly aware of the importance of igneous rocks in relation to ore deposits. They knew that some ores were concentrated by meteoric waters, but they must also have known that in most cases the work had been done by magmatic waters, as is proved by the cutting of ancient shafts in or near igneous rocks where no trace of ore was in sight; it also appears that they knew that some metals were apt to occur in basic rocks and others in acid rocks. The writer noted evidences of their geological criteria at Mount Pangeon and Cassandra (Macedon), and at Montamiata and Bottino (Italy); but further observations are necessary to establish the importance of ancient geological knowledge—observations which are still possible, even though our modern mining industry has removed a large part of such evidence.

Mining and Quarrying.—Modern mining systems do not differ greatly from ancient ones, though the means at our disposal are much more powerful. Underhand stoping was the system most employed, but they also left pillars (ὄρμοί) which were mined last, as Pliny states, by starting with those farthest from the entrance (*ab ultimo cædunt*). In such cases the country rock was left to subside, but frequently filling was used. The necessary material was carried in the same bags or baskets (θυλακος, δάλαξ, περίοδος), in which the ore was taken out.

The tools employed were hammers,[16] chisels, picks, and wedges, and when unusually hard rocks were encountered,

[16] Daubrée, *op. cit.*

as quartzite and granite, Pliny says that iron battering rams about 100 lbs. in weight were used. In Egypt, Diodorus informs us that fire was sometimes used to attack rocks, and Pliny mentions the same usage in Spain; probably it was commonly used where conditions were favorable. Limestone, it has been stated, was attacked with vinegar or other acid liquids.

A tool of great importance in quarrying was the saw[17] (λιθοπρῖστης, πρῖων)—a blade of copper or iron without teeth, not unlike those now employed. A sand of Naxos emery or other hard material was rubbed over the rock by the blade to make the cut. In Egypt trepans were used for boring in connection with the sawing, in order to cut blocks of marble or other rock from the quarry walls.

Mining tools have been found at Huelva, Spain; at Aveyron, France, at Cartagena, Sardinia, Laurium, Cassandra, and many other places. A saw 4.50 meters in length and 4 millimeters thick was found in the Feldsberg quarries.[18]

Tunnels (ὑπόνομος, διῶρυς, δῖαδυσις, ὀρίγματα, συριγγες) and shafts (φρέατα) were frequent. At Laurium, Greece, the shafts were rectangular or square (1.30 to 2.0 meters wide), and vertical, and served for hoisting and for ventilation. At Cassandra they were less regular, whereas in Spain and Sardinia they were sometimes no more than one meter in diameter. The shafts used as passageways had two series of small cuts on their sides, forming a sort of stairway. The depths reached are of course variable, but frequently they go down more than 200 meters.

When long tunnels for dewatering mines were necessary, a series of shafts was opened along them, as at Sotiel Coronada, southwest of Rio Tinto, in order to maintain the air supply near the working front. Twin shafts were connected when the distance from the surface was considerable, thus insuring ventilation even in the shafts; or the shaft was divided by a

[17] Pliny, XXXVII.

[18] Cohausen, V., and Woernen, E., "Rüm. Steinbrücke auf dem Feldsberg a. d. Bergstrasse," Darmstadt, 1876.

vertical partition to obtain a natural draught. Frequently ventilation was improved by a chimney prolonging one of the twin shafts, and it is inferred by the writer from traces observed at the bottom of ancient shafts at Mount Pangeon that fires were built at the bottom of the shaft for the same purpose.

Ventilation was regulated by boring shafts on hilltops with openings in the valleys below. Doors were also used to direct the air currents to different parts of the workings. Pliny states that they ventilated shafts and tunnels by agitating linen cloths, but does not explain further; probably they had

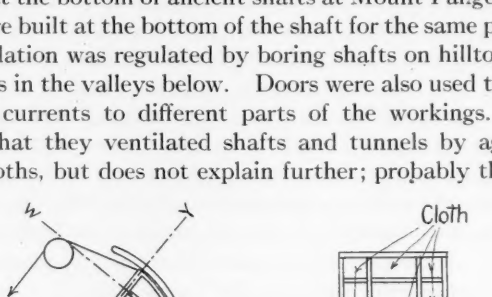


FIG. 1. Sketch showing ventilation by means of cloth flaps.

appliances like that of Fig. 1, since the writer found at Mount Pangeon a shaft with hinges placed on its brim.

It is astonishing to observe the intensity of mining in the ancient districts. At Rio Tinto seven or eight levels were discovered, one above another, and a large number of shafts. At Campiglia, Italy, areas 70 or 80 meters wide and sometimes more than 200 meters deep were entirely removed. In the mining district of Laurium more than 2,000 shafts were counted and over 140,000 meters of tunnels were measured. In another paper [19] the writer has pointed out the extent of

[19] ECON. GEOL., vol. 23, pp. 671–680, 1928.

the work done at Cassandra, and conditions are similar at Mount Pangeon and other mining districts in Greece, Thrace, Asia Minor, Egypt, and North Africa. At Huelva an adit level 1,800 meters long was bored, and at Rio Tinto, one of 2,000 meters—gigantic works which were at the very foundation of all the civilizations of the past, and bear silent testimony to the achievements of long ages.

As to the number of slaves working in the ancient mining districts we have little information, nevertheless we know that under Pericles' rule[20] there were about 20,000 slaves at Laurium. Evidently we must consider this number to represent all the inhabitants, including old men, women, and children. A large part of these would be employed as carriers or in ore dressing plants, so that I estimate that not more than 600 to 700 were actually engaged in mining in the stopes. At Cartagena, we are told by Polybius[21] that the number of resident slaves was about 40,000. Further details on this point seem to be lacking in the ancient writings.

Work went on day and night without interruption,[22] on two shifts of ten or more hours. The length of time that a miner's lamp would burn before going out was approximately that of a shift. We are told that life was very hard and sad for these poor workers, far down in the human scale, especially for the carriers, who had to transport heavy burdens from the bottom of the mine to the surface through narrow, steep passages. We have even now an instance of such painful toil in some of the sulphur mines of Sicily. The slaves of ancient times had no more opportunity to revolt than have horses or other domestic animals today; however, life at Laurium became so unbearable at one time that even these unfortunates found sufficient strength for rebellion.[23]

It is interesting to note their procedure in mining auriferous gravel (ψαμμος χρῦσῖτις). Pliny tells the story as follows: "Large

[20] Ardaillon, "Laurium," pp. 98–101.
[21] Polyb., XXIV., 9.
[22] Diodorus, V., 8; Pliny, XXXIII., 70, 97.
[23] Thucydides, VII., 27, Athens, VI.

reservoirs of water were stored at a convenient height above the gravel deposits and connected with the gravels by a very steep canal (*corrugia*). The water descended with great violence, and the gravel was carried through a long sluice cut here and there at convenient intervals by fagots of small sticks and branches. In this way the gold was collected, and since the entire section of the current was filtered, all floating particles were saved. The water used was clean and well filtered."

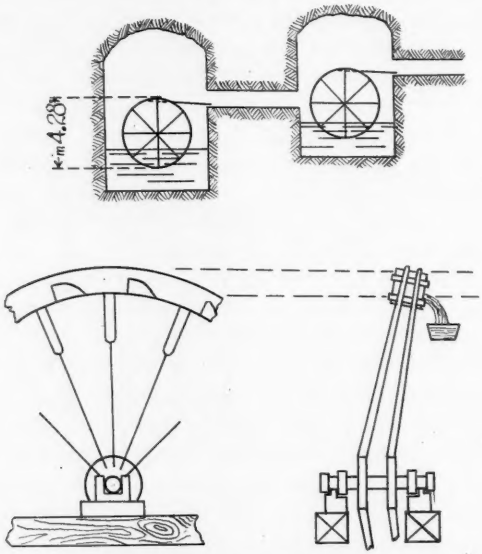


FIG. 2. Dewatering wheels.

Amalgamation was practiced in those days.[24] Mercury and gold ore suitably ground were mixed in an earthen vessel and violently agitated. The resulting amalgam was then pressed in a leather bag. The elements of modern practice were known, though exact details are lacking.

[24] Pliny, XXXIII., 99.

Appliances for Dewatering Mines.—Bateman[25] has mentioned dewatering bucket wheels (κοχλία, tympanum, rota) and Archimedes screws seen by him at the Rio Tinto mines in Spain. At the Coronada workings were found three Archimedes screws 3.6 meters long and 0.48 meters in diameter. These were placed one above another to raise water to the desired height.[26] At Tharsis (Huelva) were found dewatering wheels like that in Fig. 2, and at the Domingo mines, in Portugal, there were discovered fourteen pairs of such wheels, which raised water to a height of 44 meters.[27] All these appliances were tended day and night by slaves.[28] Bellows pumps were probably also employed, and from fragments

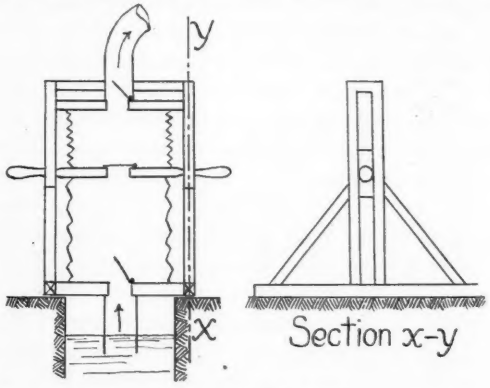


FIG. 3. Dewatering by bellows pump.

found at Cassandra the writer concludes they were of the type shown in Fig. 3.

The principle of the Heron fountain was also applied, and from traces of basins observed at the Bottino mines, in Italy, it would appear that the system for dewatering was that of Fig. 4. The same principle is now utilized in the lead mines

[25] Bateman, Alan M., "Ore Deposits of the Rio Tinto," ECON. GEOL., vol. 22, 1927.
[26] Strabo, III.
[27] Daubrée, *Rev. Arch.*, 1868.
[28] Pliny, XXXIII., 97.

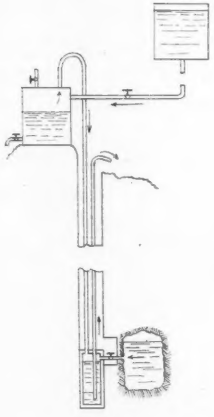
at Schemnitz, Hungary. The facts above mentioned are all that have been learned, but this appears sufficient basis to establish the skill of ancient miners in dewatering their mines. It should be added that mechanical contrivances were used only in large mines. In the small ones, which were in the majority, water was removed in buckets on ropes or chains, or was carried by slaves in rawhide bags.

Hoisting Machinery.—Ancient writings do not inform us whether mechanical devices were used in hoisting ore, but in certain places it is evident that some form of machinery was developed. The general custom, however, was to carry ore in bags and hoist it by means of ropes. Hoisting machines were so generally employed throughout Germany in the Middle Ages that we must conclude they originated in ancient times.[29] In fact, in the Nurra mines, in Sardinia, the remnants of a capstan have been found,[30] and it is known that cranes and other mechanical devices were in use in harbors or loading and unloading ships, as well as in quarries for moving blocks of stone. At Paros, Greece, for example, marble was cut underground and large blocks were raised along inclined planes. From indications found there I was able to determine that the system used was extremely simple. Rows of strong pins were fixed solidly on both sides of the inclined plane at convenient distances. Three differential capstans (Fig. 5) were employed for rolling up the weight, and were shifted upward from one pin to the next. The same system was generally used in lowering blocks from the quarries to the road, only in this case no capstan was used, but three strong ropes were turned three or four times around the pins and slowly released as the weight descended. The friction of the ropes against the pins acted as a brake to retard the speed. Special workers were necessary for such a difficult task. This ancient mode is still in use in the famous marble quarries at Carrara, Italy. The blocks are firmly fastened on a sort of sledge, which slides upon a double set of rollers

[29] Georgii Agricolae, "De Re Metallica," Basle, 1561.

[30] Teodoro Haupt, "Resoconto del mio Servizio in Italia," Florence, 1889.

sloping toward the center of the road. As the sledge passes, the rollers from behind are brought forward. No better substitute has been found, though many attempts have been made to improve the system; but over rough ground for several miles any stationary mechanism with ropes as long as the



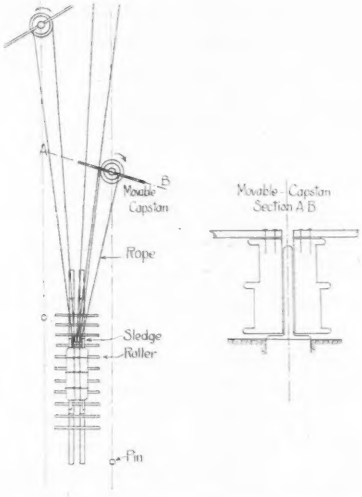


FIG. 4 (left). Dewatering by Heron fountain method.

FIG. 5 (right). Hoisting machinery used at Paros.

haul has proved impracticable. It is of interest to note that the workers are still called *lizzatori*—a corruption of the Greek name λιθαγογοῖ.

Ore Dressing Plants.—References to this subject in ancient literature are scanty. In a general way it is known that ores were ground, washed, and smelted; *quod effossum est tunditur, mulitur in farinam, lavatur, uritur;* and the Greeks had about the same sequence: τῡπτειν, χῡπτειν, ἀλήθειν.[31]

In small plants mortars of hard stone such as trachite or

[31] Strabo, III., 28; Diodorus, III., 13.

quartzite (*αγγεῖα λίθινα, ὄλμοὶ λίθινοι*),[32] with pestles (*ὔπερος*) of iron, were used for grinding ore. But where the work was sufficiently important, mills were used that resembled those used in ancient Pompeii for grinding wheat. At first the ore was ground to the size of grains of millet (*χένγχρος*), in a mill called *χενγχρεῶν*, but grinding was usually more thor-

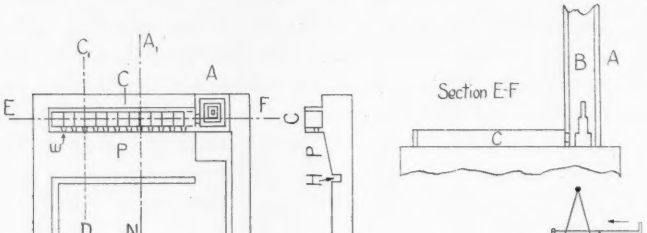


FIG. 6. Detail of ancient ore-dressing plant.

ough, reducing the material to flour.[33] Agatharchides notes the Egyptian practice in grinding auriferous quartz; it was first reduced to grains as fine as vetch seed (*ὀράδου τομεγεθος*) and afterward ground to flour (*εἶς σεμιδαλεως ἰρῦπον*).[34]

One of the most important phases in ore dressing practice was the recovery of valuable products by washing (*πλῦνειν*); many of these plants have been found, especially in Greece, at Laurium, but they were never complete, so it is difficult to follow the whole procedure. The writer believes, from observations made at Cassandra, in Asia Minor, and elsewhere, that jigging was a current practice.

[32] Theoph., "Lap.," VIII., 58.
[33] Demosth, XXXVII., 28.
[34] Agath., "Geo. Graeci Min."

The general lines of the ore-dressing plant as often found are shown in Fig. 6. Detail *A*, observed by the writer at Lipzada (Cassandra), has thrown much light on the ancient practice. Water was precipitated from a high basin into the vertical canal *B*, where it was partially emulsified with air, and went foaming to *C*, to be afterward distributed through the vents *W* in a sheet of uniform thickness along the inclined plane *P*. We are informed that the finely ground ore was distributed by a shaking sieve *S* (σάλαξ, χῶσχινος) on the foaming water,[35] and the metallic particles thus retained on the surface were caught by the blade *M*, which separated the upper layer, carrying the useful minerals and the lower, carrying barren material. It is not known whether they added vegetable or animal oil to the water; the mud deposited in the channels *H* was recovered and sifted again through the sieve *S*.

The platform *N* was sometimes 20 meters long, and afforded space, it would seem, to dry the recovered products. Hand sorting was evidently of prime importance, and enabled the economic geologist to obtain data for his underground work from the ore dressing and smelting plants. The many ingenious appliances for washing ore used in Germany [36] in the Middle Ages were certainly known, at least in part, to the ancient miners.

Smelting Practice.—When gold was found in nuggets, no smelting was done; but auriferous quartz or other gangue (*aurum canalicium*)[37] was smelted twice, first in a furnace heated by a hot straw fire,[38] then in cupels in an earthen crucible; *tasconium*, mixed with lead and alum,[39] and pure gold (χρυσιον ὀδρυζον, *aurum obruzatum*) were thus obtained.

The litharge of the cupellation was again reduced to lead with charcoal, and sold under the name of *plumbum nigrum*.

[35] Poll., VII., 97.
[36] Georgii Agricolae, *op. cit.*
[37] Pliny, XXXIII., 68.
[38] Strabo, III., 2, 8.
[39] Diodorus, 14; Pliny, XXXIII., 60.

The smelting furnaces were built on hilltops or in elevated locations when possible, to reduce gas nuisance.

Copper smelting was a twofold process. The material first obtained contained sulphur, iron, lead, zinc and silicon; it was then re-smelted with metallic lead. This is about all that is said by ancient writers as to copper smelting. Tin smelting was also a double process; the stanniferous sands were first concentrated and afterward smelted in a furnace not unlike those used for other metals.[40]

The furnaces used were usually of a crucible type, and as they were small and easily controlled, smelting phenomena were undoubtedly better known, though empirically, to the workers than in these days. The use of flux[41] was not general, and was probably a secret not known to all smelters. We are not well enough informed on this at present to make a definite statement. What we do know, however, is the enormous destruction of forests wrought by ancient smelters. The vast forests of Cyprus, for instance, were wholly destroyed in the copper smelting practice,[42] and practically the same destruction resulted in every mining district.

It is noteworthy that the decline of ancient civilization seems to coincide with the most flourishing industrial period, when quantity was considered more than quality by that voracious State, the Roman Empire. After the lamentable downfall of that spendthrift people, the darkness of the Middle Ages spread over all Europe. It is not certain that modern civilization is wiser than that of Rome.

It is somewhat surprising to find in the ancient slags at Sardinia, Spain, and at Laurium, a lead content of from 12 to 30 per cent., whereas cupellation was thorough, and left no more than 1 to 20 gr. of silver per 200 lbs. of lead. It is possible that the first smelting was purposely careless here as in copper smelting. We are told, however, that slags (σχωρῖα) were sometimes re-smelted.

[40] Pliny, XXXIV., 67.

[41] De Launay, *Ann. des Mines*, 1889.

[42] Strabo, XIV., 6, 5.

As already stated, even the higher officials in the mines were commonly slaves, but later on, the managing engineers of quarries (ερχεπιστατης τοῦ λατομίου)[43] were held in high regard, and the Romans went so far as to give them the very respectful name *philosophi*.[44] The architects (αρχίτεκτος) were employed in designing machines for carrying marble from distant quarries, and superintended their use. They also were honorably esteemed by Greeks and Romans, who appreciated the intelligent effort necessary to transport huge blocks of marble to their cities. For the miners things did not run so smoothly; work underground was not seen, and people were not aware of what went on in distant districts where only vile slaves lived. Though they made extensive use of the metals, it was easy, with throngs of deities inhabiting temples and shrines, to consider all these as gifts from the heavens; the economic geologist had nothing to do but continue his field work for the discovery of new lodes, and thus keep the whip of the slave-driver from his shoulders.

Even the "divining rod" was probably employed for mineral research by those poor slaves, to satisfy their masters. Though not mentioned by Greek and Roman writers, it is known that in the Middle Ages the divining rod was often used, as Gregorii Agricolae[45] tells us; and Pierre Belon writes in his account of a voyage to the Near East that he found the divining rod in favor at Cassandra.

Surveying.—This subject, like that of mining, is rarely mentioned in ancient literature, but it seems to the writer that geometry must have had its origin in the mining industry in the problems which had to be solved in order to locate the position of underground workings. From this dark abode geometry found its way to the Greek schools, where brilliant philosophers expanded the science of which the work of Euclid is an example. In the collection of problems in geometry and astronomy called Almagest, (so named by the Arabs as

[43] "Ephem. Epigr.," VI., p. 61, N. 160.

[44] "Passio sanctorum IV. Coronatorum," ed. Wattenbach.

[45] Gregorii Agricolae, *loc. cit.*

the greatest work of its kind), mathematics is highly developed, and very interesting is a discussion on spherical trigonometry, probably found by Hipparch, where instead of trigonometric functions as now known, the chord of the arcs was used.[46] The treatise by Aristotle on the sky is of a different nature; it is lengthy, but lacking in facts and demonstrations.

From the time of Hipparch, spherical trigonometry was known, and it is reasonable to suppose that topographic instruments were used in connection with it. Dicearch,[47] a pupil of Aristotle, measured the height of Peloponnesus Mount, but we do not know how he did this; a diopter was invented by the Egyptian Heron, and leveling instruments were used similar in principle to ours. Mention is also made of tape measures and chains (μιρίνθος).

The writer believes he has obtained sufficient archaeological information to reconstruct the instrument shown in Fig. 7. He found some years ago, in the ancient mines at Pangeon, two metallic rods joined by a hinge and peculiarly bored, but it was impossible at that time to determine their use. Recently some light has been thrown on the matter by a carved stone observed on the outer wall of the church of St. Eleuterius at Athens of which sketch is given in Fig. 9; and, remembering the peculiar rods found at Mount Pangeon, and the fact that ancient astronomers used chords instead of angles in their calculations, it was possible to reconstruct the instrument represented in Fig. 7.

The church of St. Eleuterius is one of the oldest in Athens and probably was built between 800 and 900 A.D., most of the material for its construction being taken, as was then the custom, from ruins of ancient temples and other structures of the illustrious past. Many fragments of old Greek inscriptions are visible on the walls of this small church,—mutilated remnants of what may once have been the dignified eloquence

[46] Composition mathematique de Claude Ptolémée," Traduite par M. Halma (avec le text grec). Ed. I. Hermann. Paris.

[47] Müller, C., "Frag. Hist. Graec.," II., p. 253; Strabo, VIII., 8, 7; Pliny, II., 65.

of a famous orator, perpetuated in this manner by a flattering sculptor.

In this connection it is of interest to recall that the masons of the Comacine masters' guilds[48] often carved on the walls of their buildings representations of their working tools, such as

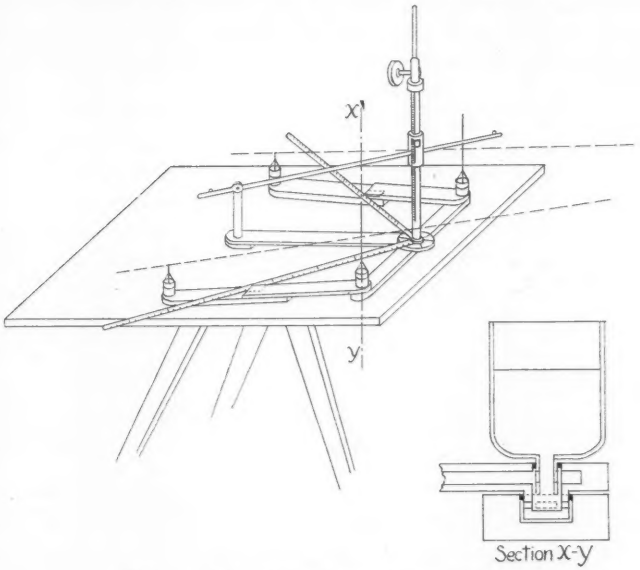


FIG. 7. Surveying table, as reconstructed.

squares, compasses, hammers, and chisels. It is logical to suppose, therefore, that the design shown in Fig. 9 may have been carved by a member of some surveyors' guild, to find its way after long ages to a resting place under the roof of a humble church.

Probably Dicearch measured the height of Peloponnesus Mount with an instrument of this kind, and the astronomers of those days may have measured, for instance, the distance of the moon from the earth, by triangulating a sufficiently

[48] Sagui, C. L., "I Maestri Comacini in Assisi:—Studi Francescani," Firenze, 1925.

long base between two distant islands of the Archipelago. The Greek poet Hesiod, of Homer's time, made the statement in poetical form that an anvil set free at the sky's vault would reach the earth in nine days and nine nights. The distance that a falling body would traverse in that length of time, according to Newton's law, is about 400,000 kilometers—not much greater than that which separates the moon from us. This would go to prove that the gravitational laws were known,

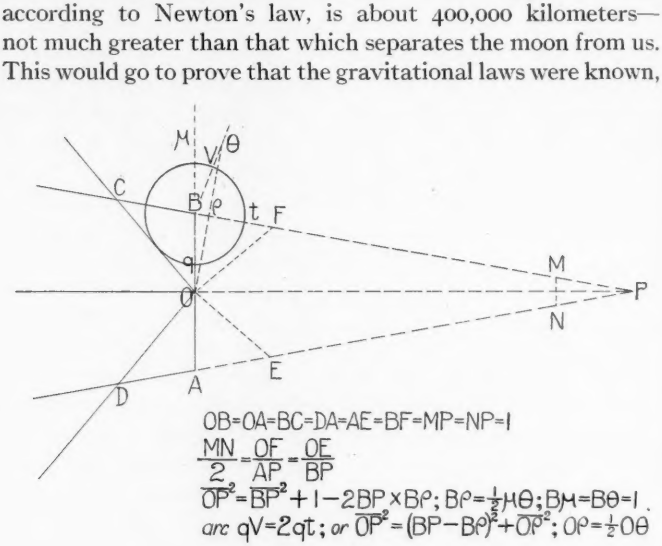


FIG. 8. Detail of Fig. 7.

as well as the approximate distance of the moon, which was then considered the limit of the sky.

Though Hesiod was probably not a scientist, what he wrote must have been common knowledge. The Near East has never yielded its secrets, and we cannot limit the scientific possibilities of the old civilizations that once flourished there by our lack of documentary evidence. Moreover, Aristotle[49] and Strabo are explicit as to the existence of the force of gravity, so that it was no longer necessary for Atlantis to hold the world on his shoulders. It was also known that the moon and

[49] Aristotle, "De Coelo."

sun were the cause of the rhythmic ebb and flow of the tides.[50]

General Geology.—The Greek scholars, like ours of today, had differences of opinion as to geologic phenomena, and we find in the scanty literature which has reached us that there were two schools, one Plutonic and the other Neptunian, concerning the formation of the earth's crust, and they do not seem to have been able to reach any agreement.[51]

Fossils were studied, and Aristotle[52] made the correct conclusion from a study of the nummulites that at certain periods submergence of land had occurred, allowing the sea to spread over considerable areas. The same theory was developed by Eratosthenes, Posidonius, and others. They mention the existence of underground lakes, streams and caverns, with their subterranean flora and fauna,[53] as well as the dynamic effects of volcanic action accompanied by the appear-

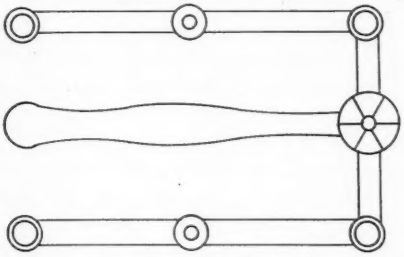


FIG. 9. Sketch from Church of St. Eleuterius.

ance or disappearance of islands or coast lines.[54] Regarding earthquakes they seem also to have had correct ideas. Democritus, for example, thought them to be caused by erosion produced by subterranean waters, and Anaximene later supposed that a progressive shrinkage of the earth was going on by cooling of the interior. Aristotle observed that the

[50] Pliny, II., 99; Strabo, I., 3, 12; III., 5, 8.

[51] "Xenoph. ap. Hippolyt. Philosoph.," XIV., (Diels, p. 566), and others.

[52] Aristotle, "Meteor.," I., 14.

[53] Senec., III., 16, 17, 19; V., 14, 15; VI., 7.

[54] Pliny, II., 88, 89; II., 90, 91.

most distinctive feature of volcanic action is the explosive force of the gases and vapors, and he concluded that earthquakes were caused by such explosions.

As to structural geology the ancients knew much more than is generally supposed. In the old workings of St. Anna, near Valdicastello, in Tuscany (Italy), the stratigraphy of the region was evidently known, as shafts were opened at distant intervals on the same geological horizon, though the lode did not outcrop.

Petrology was not unknown, and books on rocks were written by Theophrastus, Nicias, and others, though they are known to us only by fragments[55] that have survived and by quotations from them made by Pliny.

From what has already been observed, it would seem that the workings of ancient mining districts might afford a most interesting field for thorough research, in order to gain a better knowledge of ancient geologic methods.

In conclusion, it gives me pleasure to thank Professor Alan M. Bateman for his kind suggestions and help.

CORNELIO L. SAGUI.

CORBEIL,
PARIS, FRANCE.

[55] Theophrastus, περὶ λίθων, Ed. Wimmer, vol. III.

EDITORIAL

THIS JOURNAL AND THE SOCIETY OF ECONOMIC GEOLOGISTS.

WITH this number the Journal celebrates its first quarter-century of usefulness by inaugurating a new affiliation with the Society of Economic Geologists. It will continue to publish those papers presented before the Society and accepted by the Society's Publication Committee but, instead of separates of such articles being mailed to members as Society publications, each member of the Society in good standing will receive a free subscription to the Journal. In addition, the title of the Journal will be changed to indicate that it also comprises the Bulletin of the Society of Economic Geologists. The distribution of the Journal to members of the Society will commence with the termination of the current subscriptions for those who are already subscribers, and with this number for those who are not already subscribers. The Society in turn will reimburse the Journal, in part, for the subscriptions to its members. This procedure will do away with the mailing of separate reprints of Society papers to the membership, inasmuch as each member will now receive the complete publications of the Journal which will include the Society's papers as well as other articles, as heretofore. All this is being done without increase of dues to the members of the Society. Consequently, those members who previously paid for a subscription to the Journal and their dues in addition, will henceforth be saved the subscription price of the Journal and need not renew their subscriptions upon expiration. Those who were not subscribers receive a journal of which the subscription price is the same amount as the membership dues they now pay.

This arrangement should be highly satisfactory to the members of the Society, for they will now receive greater value for their

dues. It should compensate those who, for geographical reasons, are denied participation in the annual meetings, and should act as a considerable stimulus to the growth and advance of the Society. It will also supply the Society with a bulletin of its own which will carry its messages to all quarters of the globe and far beyond the confines of its membership, since the Journal's subscription list is many times greater than the membership of the Society. The subscribers to the Journal will also benefit, for they will be assured of having the advantage of receiving the papers that will be presented before the Society.

The Journal's scope will remain exactly as before. It will continue to be an independent scientific journal whose financial existence rests upon its subscriptions and whose columns are open to whoever may care to submit manuscripts, regardless of where he may live or whether he is a member of any learned society. That was the dream of its founders—that it would provide an open door to everyone, and stimulate the writing and publishing of literature pertaining to economic geology. For a quarter of a century now it has fulfilled this function. Its endeavor and that of the Society of Economic Geologists is solely to stimulate and help advance our chosen science. Together, they can achieve their objective better than separately, and we hope that under this new arrangement the Journal and the Society will achieve additional stimulus and growth.

ALAN BATEMAN.

PERCY A. WAGNER.

IT was with the deepest sorrow that we only recently learned of the death, in Johannesburg on November 11, of our esteemed colleague and associate editor, Doctor Percy A. Wagner. In early October he contracted enteric fever, then pleurisy supervened. After an encouraging improvement, a relapse set in followed by pneumonia, from which he did not recover.

His death has removed South Africa's most brilliant geologist. His writings, particularly those relating to the petrology

and economic geology of the Bushveld Igneous Complex, have given him a well-deserved worldwide reputation and his excellent investigations into the platinum deposits of South Africa have made him the outstanding authority on that subject. His monumental book, "The Platinum Deposits and Mines of South Africa," was hardly off the press before his death, and he could not have known of the laudatory reviews of it that are now appearing. Brilliant, painstaking, hard-working, and just at the climax of his fruitfulness, his death is a loss to the advance of geology in South Africa and in the world.

Those who have worked with him and felt his concentration of thought realize that strenuous devotion to his life's work had sapped the reserve of strength upon which his long illness drew too heavily.

Dr. Wagner was only 44 years of age at the time of his death. He was born at Richmond, South Africa, and received his earlier education at the South Africa College at Cape Town and the School of Mines and Technology at Johannesburg. Later he studied at the School of Mines, Freiberg, Saxony, and at Heidelberg, taking his doctorate degree in Germany. For eight years he was senior geologist in the South African Geological Survey, relinquishing this appointment in 1927 to become consulting geologist to the Mineral Exploration Company, which later became the Beckers Trust Company.

While on the Geological Survey, he wrote some twenty-six reports and articles and six memoirs. Among the latter are his well known Mutue Fides-Stavoren Tinfields (16); Crocodile River Iron Deposits (17); Magmatic Nickel Deposits of the Bushveld Complex (21); Preliminary Report on the Platinum Deposits (24); and the Iron Deposits of the Union of South Africa (26). He also prepared a special memoir on the Geology and Mineral Industry of South-West Africa. His writings did not cease with his resignation from the Survey, for many excellent articles, several of which appeared in this journal, continued to flow from his brilliant mind. His monographic book on platinum is a fitting climax to his fruitful career.

His writings were not entirely geological, for his interest in archaeology expressed itself in several articles. He also contributed to the University of the Witwatersrand a valuable collection of mining implements, smelter appliances, and metal work of the people who dug for copper, iron, tin, and gold before the advent of the white man into South Africa.

It has been a never-ending source of wonderment to his many friends how he found time to accomplish the vast amount of literary work by which he will long be remembered. The results of his professional investigations have enriched the geological knowledge of the world and have done much to make South Africa one of the great mineral countries.

Those of us who had the pleasure of making his acquaintance at the time of the International Geological Congress in South Africa came to appreciate not only his brilliant mind but also his charming personality. His winning smile, his engaging manner, his courtesy, and his scientific generosity endeared him to all whom he guided on the excursions. He previously had our respect; he won our liking.

As an associate editor of this journal, he always had its interests at heart. The excellence of his articles in its volumes has been commended by our readers, and his editorials have carried inspiration throughout the world. We feel his loss keenly.

All of us who had contact with him or have known of him share his loss with his family and with South Africa.

ALAN BATEMAN.

DISCUSSION AND INFORMAL COMMUNICATIONS

SUPERGENE CASSITERITE IN TIN VEINS.

Sir: In his paper "The Problem of Supergene Cassiterite in Bolivian Tin Veins"[1] Dr. J. T. Singewald, Jr., analyzes the data obtained in a painstaking search through the literature bearing on this subject. He classifies the evidence under four groups of criteria, namely (1) geological, (2) mineralogical, (3) chemical, and (4) textural. It would have been desirable to have included a fifth group, topographical, or at least to have given such evidence greater weight in his geological group, as it is perhaps the strongest evidence that could be offered, and in it the personal equation enters to the least extent.

Singewald realizes that the very common near-surface enrichment of Bolivian tin veins can not be explained by attributing this localization to primary agencies. The idea that a primary enrichment, that is, a segregation produced at the time of vein formation in Pliocene or perhaps even in Cretaceous time, should faithfully and obligingly follow the profile of a 20th century topography, is so absurd that it can not be entertained.

In seeking a more reasonable explanation of such topographic control of enrichment, as exemplified by the Salvador and the Kala-Uyu mines, to mention just two instances, Singewald returns to the residual enrichment hypothesis. He says (p. 345) that if the pore space of oxidized tin ore were filled with sulphide instead of air, a much lower grade tin ore would result. In the first place, in the Bolivian "pacos" or oxidized ore, the original sulphide, which was mostly pyrite, was not replaced by air but in very large part by limonite; but even assuming that the sulphides were entirely removed without leaving any other minerals as

[1] ECON. GEOL., vol. 24, pp. 343–364, 1929.

heirs, a simple arithmetical calculation will show the inadequacy of the process to account for the enriched zone. Thus an ore containing as high as 40 per cent. sulphides and 1.5 per cent. tin would have its grade raised to only 2.5 per cent. tin, even if every vestige of the sulphides were removed and replaced by air. Furthermore, such enrichment must necessarily cease abruptly at the bottom of the oxidized zone, whereas it usually enters the sulphide zone; slightly so if the vein is tight, and to a considerable extent if the vein is fractured permitting the downward percolation of meteoric waters, as witness the deep extension of rich cassiterite in the San Fermin vein precisely in the post-mineral fault zone.

Singewald mentions (p. 345) some mechanical transportation of cassiterite in the zone of oxidation. Since the paper deals with general enrichment, the author could not have referred to insignificant local droppings of ore from the top to the bottom of a vug or cavity, involving 2 or 3 meters at the most. However, it is difficult to conceive of a vein whose physical condition would permit of downward filtration of solid particles through the underlying veinfilling.

In an attempt to explain the conception of topographic control of enrichment, he shows (p. 351) that some mines exhibit vertical variation in tenor and that among the many outcrops only those were chosen for exploitation that show workable ore, and that the vast majority of Bolivian tin mines, lacking capital, were not systematically explored beyond or below the commercial ore-shoot near the surface, thus giving a false idea of the relation of rich ore to the surface. This optimistic suggestion is a very hopeful note for the future of Bolivian tin mining and should be eagerly accepted by mine owners who have already exhausted their rich surface ore shoots and to whom the theory of supergene enrichment of tin is an iniquitous heresy. The suggestion may seem plausible without a knowledge of the history of Bolivian tin mining, but I may add that in Santiago there is an extensive cemetery of defunct Chilean tin companies which did explore "beyond and below" quite in accordance with Singewald's ideas.

Nor can it be said that they lacked money or enterprise since nearly all of the big Bolivian tin mines were originally developed by Chilean capital.

The Caracoles mine is mentioned as an example where known ore-shoots have terminated repeatedly, but this company, having adequate financial resources, was able to push through the barren vein areas. This is not altogether to the point, as no one disclaims the existence of primary oreshoots, but the author does not inform us as to whether a surface enrichment was noted at this mine, or if the lower shoots were identical in character and grade with the deposits lying nearer to the surface. Incidentally, it may be said that this very progressive company, which is not overlooking anything worth while, is not acquiring the cheap properties of any of the numerous bankrupt mining companies who began with rich near-surface oreshoots, even though, according to Singewald's theory, such properties should be attractive exploration ventures for a strong mining concern.

The author warns us to keep in mind the paucity of quantitative data and speaks of stope sheets being necessary to furnish determinative data for the solution of this problem, expressing his belief that such information has not been available to those who have discussed the distribution of the tin content of Bolivian veins. Having had, in a professional way, exceptional opportunities to study closely the stope sheets of nearly all the more important producing mines of Bolivia, I must agree with Singewald that they do throw a great deal of light on the problem, which may have had something to do with confirming my belief in supergene enrichment of cassiterite. Unfortunately I can not share this source of information with the author, as such stope maps are private property and can not be made public.

Singewald abstracts from the articles of a number of observers on Bolivian tin deposits, and although all practically agree upon the basic fact of enrichment at upper levels, only about half of this number believe in supergene enrichment. On the other hand, the opponents of this theory were nearly all influenced by the heretofore generally accepted belief in the insolubility of cassiterite.

The author takes up the mineralogical evidence and again cites a number of observers. There is a really remarkable agreement as to the facts observed. Moreover, in the interpretation of this evidence, nearly all these observers admit that it indicates supergene tin. Singewald, however, overrides their testimony, saying that mineralogic criteria can not be marshalled in support of important secondary tin enrichment in these veins. In this connection, it is pertinent to recall the case of the Salvador mine near Pazña, cited by the author. In this mine the veins striking down the mountain side were worked for rich tin oxide ores in a zone concentric with the surface. Below and beyond, the rich tin ore passes into very low-grade tin, but high-grade zinc sulphide values, to such an extent that this former tin-silver mine is now considered to be a very fair zinc mine. If the rich tin zone is hypogene, with tin above zinc, a mess is made of the carefully worked out zonal relationships of Emmons and Spurr. On the other hand, if it is a supergene concentration of the sparse tin content of a high-grade zinc sulphide vein, the zonal column is left unimpaired.

The author then takes up the chemical evidence, referring to the negative results obtained in the solution tests of Gruner and Lin on cassiterite from Saxony and in those of Scrivenor on Malayan cassiterite. He also gives the evidence of Kittl and Careaga to the effect that they had not seen any cassiterite with corroded crystal faces or evidence of secondary alteration.

In support of supergene cassiterite he refers to Collins, Davy, Koeberlin, Greene, Wagner and Winkelmann as offering evidence of varying weight. He also refers to the theoretical deductions of Spurr and Boydell in favor of the solubility of cassiterite. The strongest evidence is that of Greene, who, by actual experiments, proved a rate of solution, adequate to have dissolved and reprecipitated the largest Bolivian orebodies several times over, since the date of their birth in Tertiary time. Even more comprehensive are the recent solution tests of Fink and Mantell,[2] whose paper seems to have escaped the author's search. These investigators, in an effort to develop a suitable metallurgical leach-

[2] *Eng. and Min. Jour.*, vol. 125, pp.201–206.

ing process for Bolivian concentrates, made many hundreds of tests over a period of several months. Although they failed to find a metallurgical solvent, they say: "Geologically the solubilities of cassiterite observed in our work are appreciable. The solubilities observed seem to support the solution theory of enrichment." And again: "On the whole, the values found for the solubility of tin compounds from Bolivian concentrates may bulk large from a strictly geological view-point."

The foregoing exhaustive series of tests by independent investigators furnishes positive experimental evidence of the solubility of Bolivian cassiterite. By its very nature positive evidence outweighs negative. Furthermore, the negative experimental evidence that is offered, has to do with the purer cassiterite from Saxony and from the Straits, and not with Bolivian cassiterite, the subject of the author's paper. Notwithstanding, the author still speaks of "preponderant evidence against solution," and that, "available evidence does not make out a conclusive case either for or against the deposition of supergene cassiterite."

Finally, after having dismissed the field evidence and the chemical evidence favoring supergene enrichment, the author tells us that the advocates of enrichment have completely overlooked the line of evidence offered by the paragenetic relations of the ore minerals in the vein filling. I certainly hold that all existing evidence should be duly considered in accordance with its weight, but do protest against the attempt to set up the microscope as a court of last appeal. In the present state of our knowledge, what positive criteria, it may be asked, have we for distinguishing supergene from hypogene cassiterite? Singewald (p. 360) quotes Boydell as saying that "the really essential point is to establish the deposition of cassiterite (in considerable quantity) on later minerals of the paragenetic sequence (those minerals being the sulphides and silver minerals)." Immediately following thereupon he cites Kozlowski as saying that in the Potosi ores bands of compact cassiterite alternate with bands of stannite, tetrahedrite and pyrite. Tetrahedrite as freibergite "cochiso" is the principal silver-bearing sulphide mineral of this section of Bolivia, so

according to Singewald's criterion the band of cassiterite following upon a band of tetrahedrite should be supergene. Personally I believe that in this particular case the cassiterite is hypogene, since silver tetrahedrite is a typical primary silver mineral in the deepest levels of Bolivian mines. It merely goes to show the untrustworthiness of the proposed criterion. This criterion also requires the deposition of cassiterite "in considerable quantity" on the later minerals of the paragenetic sequence. I fail to see how the quantity factor can be determined in a slide, but referring again to the Salvador mine, where a rich tin zone, a kilometer or more in length (surely a considerable quantity), passes into underlying zinc sulphide; would a slide or polished section showing a deposition of cassiterite on zinc sulphide make this cassiterite any more convincingly supergene? Probably not, as no weight is given to the occurrence of needle or honey tin on the late mineral wurtzite, mentioned by Greene (p. 36). It seems hopeless to find any mineral late enough in the paragenetic sequence to be convincing, since even the bones partially replaced by cassiterite, mentioned by Professor Davison of the Camborne School of Mines (p. 357), leave the author unimpressed.

I have seen perfect casts of pseudomorphic cassiterite after pyrite from the oxidized zone of the Rosario mine near Colcha; stalactitic cassiterite from the Jatunkaka property, also near Colcha; but these are merely additional straws of evidence. I have seen slides showing scattered and broken coarse crystals of cassiterite imbedded in a much finer-grained cassiterite, evidently of another generation. Knowing something of the field relations of these specimens, I should have ascribed the second generation to supergene agencies. The microscopist, however, reported them both as hypogene, giving as his reason that since cassiterite is insoluble, the second generation could not possibly be supergene, so necessarily it must be due to a later surge of hypogene solutions. This may probably be one of the principal reasons why so little supergene tin has been seen through the microscope.

One of the great handicaps of the microscopical workers, as I

have been assured by Dr. Berkey and Dr. Kerr of Columbia University, is that they so seldom have the opportunity to collect their own specimens. Not knowing the field relations of the specimens with which they are working, they do not have the benefit of the auxiliary data that such knowledge would give them, which would greatly aid them in the interpretation of the facts observed under the microscope.

The usual source of the material examined by the worker with the microscope are the suites of specimens from some mineralogical museum or collection. These specimen suites commonly were not collected for the purpose of elucidating some specific problem like supergene tin enrichment, which in itself would require painstaking care and judgment in the selection of the sample. Ordinarily they have been gathered at random by someone, and have been examined by someone else who was without a clear idea of the field relations of the particular specimen under examination. Furthermore, specimens that find their way into museums and collections are the showy, pretty pieces with clear-cut crystallization, which by their very nature are more likely to be of hypogene origin, not the dirty, confused, indeterminate, even though rich stuff, which does not appeal to the eye, but which is precisely the form in which supergene cassiterite would be most likely to appear.

Singewald finally submits what he describes as "imposing" evidence against supergene cassiterite enrichment. Buerger and Maury, studying a suite of specimens collected by Lindgren from the Colorado vein at Chocaya, establish the hypogene origin of the minerals involved. The Colorado vein is the same vein that I had already mentioned in my first paper, cited by the author, as an outstanding example of a primary vein. Consequently, nothing is gained by insisting upon the hypogene character of the ores from an admittedly primary occurrence. Davy, working upon suites of ores gathered by different collectors, considers the cassiterite as hypogene. The following quotation from the article referred to is illuminating: "Cassiterite is relatively insoluble in acid waters and consequently the

source of the tin for the great quantities of 'wood-tin' present could hardly have been the oxide." In justice to Davy it should be mentioned that his paper was written long before Greene, and Fink and Mantell had established by laboratory experiments that Bolivian cassiterite was soluble to an appreciable degree. The photomicrographs submitted with Davy's paper lend themselves as readily to supergene as to hypogene interpretation. Hall examined Singewald's collections with the same result. Creveling studied a suite of specimens which were brought by Lindgren from Potosi a number of years ago. Cassiterite is presumed to be hypogene. However, Fig. 6 and Fig. 11 of the cited paper are just about as convincing for a supergene as they are for a hypogene origin. In other words, they neither prove nor disprove. Winkelmann, working upon a suite of ores collected by Professor Scheibe, finds cassiterite older than arsenopyrite, pyrite and marcasite, which Singewald classifies as "undoubted primary sulphides." Yet in the tin veins of Llallagua, stalactites of this so-called primary marcasite over one foot long have been found. Kittl states that no cassiterite younger than stannite has yet been observed;—by himself, it should be added. since Kozlowski as well as Buerger and Maury find repeated cycles of cassiterite and stannite. Second cycle cassiterite must necessarily be younger than first cycle stannite, so this invalidates another criterion. Careaga recognizes cassiterite only as an early hydrothermal mineral. His specimens were taken from the same Colorada vein of the Oploca Company, Chocaya La Vieja mine, which has already been mentioned in this discussion. From the very first I named this vein as a case where supergene enrichment did not take place, consequently, it cannot be cited as evidence of non-supergene origin.

This then, is the evidence with which the author proposes to nullify the large-scale field evidence which lies open to the world and can easily be verified, and the positive chemical results obtained experimentally. In none of the paragenetic studies referred to is it clear that the samples were collected with this problem in mind. Such studies can furnish only weak evidence unless such work is done on representative specimens carefully

selected from debatable zones, and preferably by the microscopical worker himself.

Singewald closes with the statement (p. 362) that "the available evidence does not warrant the conclusion that the Bolivian tin veins present the unusual phenomenon of important supergene cassiterite enrichment." Since throughout the paper the qualifying adjective "important" is used it may be that the author is willing to concede that it does take place to an unimportant extent, which after all would signify some progress. In the meantime the dozens of extinct mining companies who begun with rich surface oreshoots, and the scores of long tunnels and deeper workings, with which they tried to find the continuation of these shoots beyond and below, are mutely eloquent as to the quantitative aspects or commercial importance of the process.

SANTIAGO, CHILE. F. R. KOEBERLIN.

THE IRON DEPOSITS OF THE SIERRA DE IMATACA, VENEZUELA.

Sir: The iron deposits of the Sierra de Imataca, which occur in the Northern border of the Guayana highlands of Venezuela, have lately attracted much attention on account of their economic possibilities. The present writer examined the deposits in the field, and found them of exceptional interest.

The geology, as well as the character of the ores, seems to be remarkably similar to that of the iron ore deposits of the Province of Central Minas Geraes, in Brazil, as described by E. C. Harder and R. T. Chamberlin.[1] The similarity is so evident that it is believed by the author that one theory of origin may apply to the ores of the two regions. The Imataca deposits have so far been considered as an example of the Brazilian type of occurrence, and no attempt has been made to explain their origin.

Results have been obtained which disagree with the hypothesis of origin advanced for the ores of Minas Geraes, so it has been considered advisable to present this preliminary communication.

The Sierra de Imataca is a mountain range formed by the remnants of a sedimentary series of pre-Cambrian or Paleozoic age, mainly quartzites. It borders the Orinoco river in the last

[1] *Jour. of Geology*, vol. XXIII., 1915, pp. 341–378 and 385–424.

five hundred kilometers of its course, as a series of flat-topped hills. The upper peneplaned surface of these hills is approximately 200 meters above the surrounding plains of the basement complex, in which a thin veneer of recent sediments covers the igneous rocks. The Orinoco River separates the Guayana Highlands from the very different physiographic province of the Llanos, where thick tertiary formations exist and exploration for oil is being carried on.

Many iron deposits occur in the Imataca range; some of slight economic importance, others which may rate with the largest masses of high grade iron ore of the world.

These deposits, as well as the Brazilian ones, are characterized by the presence of the banded iron formations or "itabirites," in which the iron minerals, mainly hematite and magnetite, are present in a sedimentary rock, generally a sandstone, now more or less metamorphosed to a quartzite. (In the Pao deposits in Venezuela, such structures are so obscured as to appear to be purely igneous deposits, yet banded quartzites are present.) Among these formations, local, lens-like concentrations occur, some conformably with the sedimentary structure, others cutting across them. Some of these concentrations are large masses of almost pure hematite.

In many places, weathering has leached much of the silica away, leaving a conglomeratic ore, several meters thick, the "canga" ore, which forms a blanket over the bed rock of the formations with a table-like structure, which suggests long weathering and sedimentation at base level conditions.

The banded iron quartzites and the apparent lack of relationship to igneous rocks have been the reason for calling these deposits sedimentary, that is to say "laid down in a measure similar to limestone beds," [2] and in which the rock "is a mixture of iron oxide and quartz laid down essentially as it occurs today. The principal change which it has undergone since its deposition is the dehydration which has converted the ferric hydroxide originally laid down into ferric oxide or hematite." [2] The rich iron deposits are explained as being part of the formation, in which there was a smaller deposition of mechanical sediment, such as quartz

[2] *Op. cit.*, p. 395.

sand. "In the Brazilian ironfields . . . the itabirites and the iron ore being the original rocks."[2] This theory has been carried so far as to consider the iron-precipitating bacteria responsible for the deposition of the iron.

From field studies in Venezuela it is my belief that the richer deposits are in intimate relationship with igneous intrusives, and that the iron has been, at least in part, introduced into the sediments. There probably was some iron present which was later redeposited.

Granite is always found near the deposits in Venezuela (also in Brazil, see map *op. cit.*, page 347). This granite has so far been considered as part of the basement complex of the Guayana Highlands, and hence older than the sediments. I believe that this granite is a different one from that of the complex, and that it is intrusive into the sediments.

Field evidence for this is the occurrence of large masses of garnetized rock at the contact (especially clear at the Monte Cristo deposit, 30 kms. S.E. of Ciudad Bolívar), the presence of quartz and magnetite veins crosscutting the bedding near the contact, crosscutting veins of hematite from which the bands of iron are seen in some cases to originate, veins of hedenbergite crossing the bedding, and the occurrence of structures in the sediments concordant with those of the intrusives. It is to be remembered that quartzite is a very unfavorable rock for pyrometasomatic action, and that the contact metamorphic features are not so marked as with limestone.

The more rapid weathering and erosion of the igneous rock, (mainly a syenitic granite) compared with the resistant silica-hematite of the iron formations is believed to be the explanation of finding the bodies of iron-rock forming conspicuous hills, whereon the intrusives have been eroded to the level of the surrounding plain.

Studies of the relations of the ore minerals, of the canga ores, and of the igneous rocks related to the deposits, are now under way. I hope to be able to present a final paper within a short time.

GUILLERMO ZULOAGA.

GEOLOGICAL LABORATORIES,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

REVIEWS

The Platinum Deposits and Mines of South Africa. By PERCY A. WAGNER. With a chapter on the Mineragraphy and Spectrography of the Sulphidic Platinum Ores of the Bushveld Complex, by H. SCHNEIDERHÖHN. Pp. xv + 326, pl. 38, figs. 37. Oliver & Boyd, Edinburgh, 1929. Price, 21s.

The discovery of great primary deposits of platinum minerals in South Africa was first made known to the world about five years ago, and since that time information of their method of occurrence has trickled out in disconnected bits. The author of the present book had for his purpose the description of the remarkable Transvaal deposits in a more detailed manner than had heretofore been attempted and at the same time to describe other similar deposits in Cape Province and Southern Rhodesia. In his attempt he was ably aided by Dr. Schneiderhöhn, who contributed to the volume an excellent chapter on the mineragraphy and spectrography of the sulphide ores of the Bushveld Complex.

The platinum minerals that have been found in the various ores in Southern Africa are platinum, alloyed with palladium and gold, osmiridium, iridosmine, sperrylite, cooperite, stibiopalladinite and possibly ruthenium. Cooperite is a platinum sulpharsenide (Pt As S_2) that is probably orthorhombic. Stibiopalladinite is an isometric palladium antimonide. The sperrylite is in crystals that are remarkable for their size, some of them weighing 33.75 grams and measuring about 18 mm. in diameter. In the Lydenburg district the bulk of the platinum is in the metallic state in dunite, often in cubic crystals measuring 1 mm. across and in nuggets ⅜ in. in diameter, enclosing minute crystals of osmiridium. The metal contains small amounts of copper, nickel, iridium, rhodium and palladium in solid solution. All the platinum minerals occur in the Bushveld complex, mainly in a dark sheet of norite (the Merensky horizon), and in layers of coarse pyroxenite or harzburgite that is richly chromiferous in some districts. The ore averages about 6 dwts. of platinum metals over a stoping width of 30 inches, but in some picked specimens as much as 13 oz. per ton. Some of the platinum is in the form of the native metal and some in the platinum arsenides already referred to, but much is in solid solution within the sulphides, chalcopyrite, pyrite, pyrrhotite and pentlandite. Platinum is found also at some places in a metamorphosed limestone at the lower contact of the igneous rocks. Here the metal is again in sulphides, of which pentlandite is the most prominent one.

Another interesting occurrence is sperrylite and stibiopalladinite associated with sulphides in irregular veins and eyes of pegmatite in crush zones within banded ironstone.

One of the surprising features of the occurrence is the absence of the platinum metals from the weathered outcrop of the platinum-bearing rocks at many places. Schneiderhöhn accounts for this by assuming that since the precious metals are in solid solution with sulphides, when the latter were oxidized the platinum went into colloidal solution in the groundwater and was drained off. At other places there is believed to be evidence that platinum and palladium have been leached and redeposited on a large scale. Wherever the platinum-bearing rocks occur they are overlain and underlain by anorthosite, or anorthositic norite. This leads the author to the inference that the complex of rocks represents a differentiated series, and that the splitting of the magma and the concentration of the platinum were alike a consequence of the presence of abnormal amounts of sulphur and other mineralizers in the particular portion of the parent norite magma from which the sulphide-bearing rocks and their associates crystallized. The portions of the magma in which the mineralizers were most abundant were kept in a liquid state for a long time. The small amounts of platinum in the original magma were dissolved and concentrated in droplets of matte which the sulphur formed with the nickel, iron and copper also extracted from the magma, and these droplets were concentrated in the magnesia-rich fraction that gave rise to the Merensky and other platinum-bearing horizons. In brief, the occurrence of the platinum minerals is ascribed to the differentiation of a magma containing minute quantities of the precious metals. The first phase of the process was the separation of chromite, magnetite and the silicates that formed the norites and associated rocks, leaving a liquid sulphide melt. In the second phase this sulphide melt collected in the interstices between the crystallizing silicates and, because of its richness in fugitive constituents, reacted with the silicates, giving hornblende and biotite, while at the same time the carbon-bearing gases deposited graphite. In this phase the platinum metals entered into isomorphous solution with the sulphides. In the third phase the residual solutions, left after the separation of the sulphides, solidified as pegmatites carrying side by side definite platinum minerals (sperrylite, etc.), and non-platiniferous sulphides; and entered limestones, producing contact effects, at the same time depositing iron and copper sulphides and platinum arsenides, etc. In the fourth, or hydrothermal phase, steam and readily fugitive constituents reacted with the earlier-formed silicates and sulphides making serpentine, carbonates and millerite, and deposited highly dispersed platinum, probably in the native state.

All stages in the development of the rocks and the deposits of the

platinum minerals are minutely described. Of special interest is the description by Schneiderhöhn of the platinum-bearing minerals, which are discussed in great detail. His discussion is illustrated by handsome photographs of polished sections. Incidentally there is outlined an accurate means for detecting small quantities of elements in tiny particles of sulphides by means of the quartz spectograph and ultraviolet light. The book is well printed and handsomely illustrated with many photographs and several maps.

W. S. BAYLEY.

The Nature of the Physical World. By A. S. EDDINGTON. Pp. 360. Macmillan Co., New York, 1929. Price, $3.75.

All the world knows of Professor Eddington as the illustrious astronomer of Cambridge University, but not everyone knows of his well-deserved reputation for clear exposition of difficult subjects. This book is an example of it. It is based on the Gifford lectures delivered at Edinburgh in 1927. "It treats of the philosophical outcome of the great changes of scientific thought which have recently come about. The theory of relativity and the quantum theory have led to strange new conceptions of the physical world."

The first eleven chapters deal with new physical theories which are lucidly presented to make clear the scientific view of the world today. In the last four chapters he relates these physical discoveries "to the wider aspects of human experience, including religion."

Some of the subjects with which he deals are: the downfall of classical physics; relativity; time; the running down of the Universe; gravitation; man's place in the Universe; world building; reality; causation; science and mysticism.

It is an extremely interesting book and so clearly written that it is understandable to everyone. Every educated person should read it.

ALAN BATEMAN.

Geology and Mineral Deposits of Southeastern Alaska. By A. F. BUDDINGTON and THEODORE CHAPMAN. Pp. 398, pls. 22, maps 2. U. S. Geol. Surv. Bull. 800. Washington, 1929. Price 85c.

The results of the extensive field work carried on by Chapman and Buddington in Southeastern Alaska, as well as a compilation and consideration of many of the published data, are embodied in this report.

The section on topography is naturally dominated by the description of the glacial features and the existing glaciers. Excellent pictures add to the interest.

The stratigraphic column is rather long and complex. The description

of the Palaeozoic rocks older than the Carboniferous is of especial interest. Kerr[1] has described a section from Ordovician to Permian in the Dease River area to the east, but no rocks as old as these have been found in the Coast Range to the south. Brooks[2] and Daly[3] report Ordovician rocks from the Dean River, B. C.; however it is probably a misprint for Dease River. The Ordovician rocks consist of chert, black slate, graywacke, and andesites. The Silurian rocks are lithologically similar and may reach a thickness of 14,000 feet. The Devonian contains a large amount of volcanic material with limestones and graywacke.

The Mesozoic volcanic and sedimentary rocks are, in general, similar to those described from other localities on the west coast. They are of Upper Triassic and Jurassic and Lower Cretaceous ages. The Tertiary is represented by Eocene and Pliocene. The Eocene occupies basins, which are similar to those of the Puget trough region to the south. The Pliocene is represented by about 1,000 feet of clastic sediments and some volcanic rock.

The consideration of the Mesozoic Coast Range *batholiths,* occupies about 80 pages and constitutes one of the most interesting parts of the bulletin. The batholiths extend from the 49th parallel about 1,100 miles in a northwesterly direction. The width exceeds 100 miles in some places, and, in addition, there are outlying intrusions of batholithic dimensions to east and west. These intrusives are believed to be responsible for most of the metallization along the Coast Range.

In line with the accumulating evidence that the batholith is, in part at least, younger than the lower Cretaceous, the age of the intrusives is given as Upper Jurassic or lower Cretaceous. The variation of the rocks over a limited area is considered and a table showing this variation as determined by the Rosiwal method is given. These analyses show considerable variation of the rocks both along the strike and across it. As might be expected the variation across the trend of the range is more marked than parallel to it. It should be emphasized however, that the description of the rocks and their variation may be only applicable to the area under consideration. Several years ago the reviewer, as the result of field work and the study of the literature, concluded that the Coast Range could be divided into several segments. Each segment is characterized by a variation in history before intrusion, differences in trend, and differences in the character of the contact. Some tendency toward differences in mineralization in also shown. The area under consideration constitutes the most northern segment.

About 80 pages are devoted to economic geology. This section is of

[1] Kerr, F. A., Geological Survey of Canada, Summ. Rept. 1925, p. 32-A.

[2] Brooks, A. H., U. S. Geol. Surv. Prof. Paper 45, p. 206.

[3] Daly, R. A., Canada Geol. Surv. Mem. 38, p. 560.

greater interest to the general reader because, instead of detailed descriptions of individual mineral deposits, the discussion is general. Such things as the relationship of the deposits to lithology and structure are considered. Buddington concludes that the Mesozoic plutonic rocks are responsible for most of the mineralization in southeastern Alaska. He concludes that the view of Schofield regarding the general distribution of the deposits around the batholith with a flat contact and high temperature mineralization on the west and a steep contact and intermediate temperature mineralization on the east is applicable to southeastern Alaska only with modifications.

This Bulletin supplies a definite need: it gives a summary of the work done in southeastern Alaska and makes it unnecessary to search a rather voluminous literature for information. Furthermore, the consideration of the distribution of the mineral deposits is of interest to the economic geologist, and the sections of the report dealing with the Coast Range Intrusives should be read by every student of the batholith problem.

F. F. OSBORNE.

STATE UNIVERSITY OF IOWA,
IOWA CITY.

Geophysical Surveying. By W. H. FORDHAM, with discussion by W. R. MACDONALD, S. J. TRUSCOTT, H. B. BATEMAN, D. C. BARTON, ARTHUR WADE, H. SHAW AND A. B. EDGE. *Jour. Inst. Pet. Tech.* (London), vol. 15, No. 72, pp. 35–80, Feb. 1929.

This paper is a review of the applied geophysical methods based on Fordham's personal experience and on a survey of the literature. A brief description of the instruments and a brief statement of the elementary theory of the various methods are given. The value of the methods in prospecting for oil is discussed. Estimates of the cost of geophysical surveys are given. A brief selected bibliography is appended.

DONALD C. BARTON.

Geological Nomenclator (Geologische Nomenclator, Geologische Nomenklatur, Nomenclateur Géologique), edited by L. RUTTEN. Pp. 338, diagrams. G. Naeff, The Hague, 1929 (Sept.). Price, $8.50.

This book gives in parallel columns the equivalents of English geological words and phrases, in German, French, and Dutch. It is in no sense a mere dictionary. It gives not only the accurate translations of words in the different languages, but also sets forth equivalent geological phrases and expressions, aided, in places, by diagrams. Its purpose is the clear and accurate transmission of thought from one language to another. Everything is written in these four languages.

The contents are classified according to subjects. These subjects, and the authors responsible for them, are: Ore Deposits, H. F. Grondijs and C. Schouten; Petrology, J. A. Grutterink; Tectonic Geology, G. A. F. Molengraaff; Exogenic Processes and Physiography, W. E. Boerman and K. Oestreich; Volcanology, B. G. Escher; Seismology, G. Van Dijk; Slow Changes in Levels and Mountain Building, L. Rutten; Stratigraphy and General Paleontology, P. Kruizinga; Alphabetical Index by L. Rutten.

The excellent alphabetical index enables one to look up a desired word in either of the four languages and then turn to the page where the translations are given.

It is a valuable book for everyone who reads or writes geological literature in English, German, French or Dutch. The translation of an elusive word or phrase can be found in a few seconds. For one whose geological vocabulary in these languages is not what he would like, it is a necessity.

The book is 8 x 11 inches, is substantially bound and well printed in large bold type.

ALAN BATEMAN.

Sedimentary Petrography, 2d ed. By H. B. MILNER. Pp. xxi + 514, figs. 40, pl. 41. Thomas Murby & Co., London, 1929. Price, 21s.

The new edition of this well-known book follows closely the plan of its predecessor. The text, however, has been completely revised and brought up to date. A great deal of new material has been added to that contained in the original edition, and the number of illustrations has been doubled. The chief departure from the plan of the first edition consists in the introduction of a chapter of nearly 100 pages describing systematically all the more familiar types of consolidated sedimentary rocks. In all, 44 distinct varieties are described and 79 are pictured. The "principles and practice of correlation and differentiation of sediments have been restated in the light of more extensive experience, especially in connection with sub-surface oil geology." Another departure is in the addition of a chapter of 21 pages on the study of soils.

To those who are familiar with the good qualities of the first edition, it is a sufficient recommendation for the new edition to state that it is an improvement on the earlier one.

W. S. BAYLEY.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

BOOKS RECEIVED

BY

F. S. PARKER.

Reference Book of Inorganic Chemistry. By W. M. LATIMER AND J. H. HILDEBRAND. Pp. 442. The Macmillan Co., New York, 1929. Price, $3.75. Arranged according to groups; nineteen appendices; excellent reference.

Erzlagerstättenkunde. By DR. GEORG FREBOLD. I, Magmatische Erzlagerstätten. Pp. 103, figs. 31. Sammlung Göschen, Bd. 1014. II, Sedimentäre und metamorphe Erzlagerstätten. Pp. 97, figs. 28. Sammlung Göschen, Bd. 1015. W. de Gruyter & Co., Berlin, 1929 (Dec.). Price, 1.50 M. per vol. A small-sized compact elementary treatment of ore deposits.

Asbestos: A List of References to Material in the New York Public Library. Compiled by W. B. GAMBLE. Pp. 72. New York Public Library, 1929 (Dec.). Price, 50 cts. Extensive bibliography of occurrence, uses, and mineralogy.

The Varves and Climate of the Green River Epoch. By W. H. BRADLEY. Pp. 23, pls. 4, figs. 2. U. S. Geol. Survey Prof. Paper 158-E, Washington, 1929 (Dec.). Price, 15 cts. Characteristics of ancient Green River Basin; cycles of deposition; duration of the Eocene epoch.

The Geology and Origin of the Silurian Salt of New York State. By H. L. ALLING. Pp. 139; figs. 20. N. Y. State Mus. Bull. 275. Univ. State of N. Y., Albany, 1928 (Dec., 1929). Distribution of salt deposits, stratigraphy, sedimentation, paleoclimatology, chemistry of deposition, petrography, bibliography.

Geology of the De Queen and Caddo Gap Quadrangles, Arkansas. By H. D. MISER AND A. H. PURDUE. Pp. 195, pl. 18, figs. 9. U. S. Geol. Survey Bull. 808, Washington, 1929 (Sept.). General geology; diamonds, lead and zinc, asphalt, slate, and miscellaneous mineral deposits.

Occurrence and Origin of Analcite and Meerschaum Beds in the Green River Formation of Utah, Colorado, and Wyoming. By W. H. BRADLEY. Pp. 7, pl. 6. U. S. Geol. Survey Prof. Paper 158-A. 1929 (Oct.).

Geology and Coal and Oil Resources of the Hanna and Carbon Basins, Carbon County, Wyoming. By C. E. DOBBIN, C. F. BOWEN, AND H. W. HOOTS. Pp. 88, pl. 27, figs. 3, map. U. S. Geol. Survey Bull. 804, Washington, 1929 (Oct.). Detailed description of stratigraphy, coal and oil; numerous coal correlations and geological map.

Mineral Resources of the United States in 1928 (preliminary survey). Pp. 116. U. S. Bur. of Mines, Washington, 1929 (Sept.).

Investigations in Ceramics and Road Materials, 1927. Pp. 80. Canada Dept. of Mines, Mines Branch, No. 697. Ottawa, 1929 (Sept.).

Tests of Various Fuels for Domestic Hot-Water Boilers. By E. S. MALLOCH AND C. E. BALTZER. Pp. 92, figs. 6, pl. 5. Canada, Mines Branch, No. 705. Ottawa, 1929 (Sept.).

Sand and Gravel Deposits of New York State. By C. M. NEVIN. Pp. 180, figs. 42. N. Y. State Museum Bull. 282, Albany, 1929 (Sept.). Origin; tests; uses; exploration.

Die gravimetrischen Verfahren der angewandten Geophysik. By HANS HAALCK. Pp. 205, figs. 85. Sammlung geophys. Schriften, Heft 10. Gebrüder Borntraeger, Berlin, 1929 (Nov.). Price, 16.80 M. Theories and application of the torsion balance, pendulum, etc.

Gold Fields of Nova Scotia. By W. MALCOLM AND E. R. FARIBAULT. Pp. 253, pl. 40, figs. 10, maps 4. Canada Geol. Survey Mem. 156, Ottawa, 1929 (Nov.). Price, 50 cts. Comprehensive compilation, chiefly from work of E. R. Faribault; general geology; lode and placer gold, antimony.

Geophysical Investigations at Caribou, Colo. By C. A. HEILAND, C. W. HENDERSON, AND J. A. MALKOVSKY. Pp. 45, figs. 13. U. S. Bur. of Mines, Technical Paper 439, 1929 (Nov.). Price, 10 cts. Magnetic investigation of a known magnetite body.

The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana. By A. J. COLLIER. Pp. 189, pl. 8, figs. 3. U. S. Geol. Survey Bull. 812-B, 1929 (Nov.). Price, 30 cts.

Summarized Data of Gold Production. By R. H. RIDGWAY. Pp. 63, figs. 17, tables. U. S. Bur. of Mines, Econ. Paper No. 6, 1929. Price, 20 cts.

The Chandalar-Sheenjek District, Alaska. By J. B. MERTIE, JR. Pp. 139, figs. 2, maps 2. U. S. Geol. Survey Bull. 810-B, 1929 (Nov.). Geography, general geology, oil shale.

Suspended Matter in the Colorado River in 1925–1928. By C. S. HOWARD. Pp. 44, pl. 1, figs. 2. U. S. Geol. Survey, Water Supply Paper 636-B, 1929 (Nov.).

Surface Water Supply of the United States, 1925, Part VII. Lower Mississippi River Basin. W. S. Paper 607. Pp. 112. Price, 20 cts. Part. VIII. Western Gulf of Mexico Basins. W. S. Paper 608. Pp. 268, fig. 1. Price, 30 cts. Part IX. Colorado River Basin. W. S. Paper 609. Pp. 145, fig. 1. Price, 15 cts. Part X. The Great Basin. W. S. Paper 610. Pp. 145, fig. 1. Price, 20 cts. Part XII. North Pacific Slope Drainage Basins. *B*, Snake River Basin. W. S. Paper 613. Pp. 271, fig. 1. Price, 30 cts. *C*, Pacific Slope Drainage Basins in Oregon and Lower Columbia River Basin. W. S. Paper 614. Pp. 198, fig. 1. Price, 30 cts. U. S. Geol. Survey, Washington, 1929 (Nov.).

SOCIETY OF ECONOMIC GEOLOGISTS

Bulletin of Society.

Starting with this number, all members of the Society of Economic Geologists will receive Economic Geology as the bulletin of the Society This will supersede the arrangement whereby Bulletins of the Society are reprints, bearing the distinctive cover of the Society. The plan is to be made effective without increase in dues, which will remain Five Dollars.

By this plan of publication, duplication will be eliminated to those members who have subscribed to Economic Geology. In particular this plan will give more tangible returns than heretofore to those members who cannot attend annual meetings.

Annual Meeting.

The Ninth Annual Meeting of the Society will be held on April 24th (or 25th) to 26th at Charlottesville, Virginia, as the guests of the University of Virginia and the Virginia Geological Survey. The meetings will be followed by a one-day field trip to the workings of the Virginia Alberene (soapstone) Company and the Nelson County rutile deposits. Papers for the next technical meeting should be submitted to the chairman of the Program Committee, J. T. Singewald, Johns Hopkins University, Baltimore, Md.

New Officers.

The officers elected by the Society for the coming year are: President, S. H. Ball; Vice-President, Alan Bateman; New Councillors, E. C. Andrews, T. M. Broderick, and W. T. Thom, Jr. These will take office following the annual business meeting at Charlottesville.

Edward Sampson,
Secretary.

SCIENTIFIC NOTES AND NEWS

J. A. Bancroft, geologist in charge of field operations for the Rhodesian Anglo-American Company, has been in the United States and Canada on leave and was a recent visitor in New Haven. He left the latter part of January for London.

H. A. Brouwer, formerly connected with the Technical High School at Delft, Holland, is now at the Geological Institute of the University of Amsterdam.

H. W. Rose is now associated with Drs. Steiner and Barton in geophysical work, and has moved from Houston, Texas, to Los Angeles, Calif.

J. F. Walker, of the Canada Geological Survey, Department of Mines, is now in the British Columbia office at Vancouver, and F. A. Kerr, who has been in the British Columbia office, is in headquarters at Ottawa.

Howard E. Simpson, of the Department of Geology, University of North Dakota, and State Water Geologist, last summer surveyed the ground water resources of Regina, Saskatchewan, for the Canada Geological Survey, for the purpose of enlarging and improving the public water supply, and was also employed by the Fairbanks Water Supply Company to investigate municipal and industrial water supplies in Massachusetts and other Eastern States.

Frank L. Hess returned to the United States in November after four months of professional work near Canton, China, and five months in the Malay Peninsula, Ceylon, India and Italy.

S. G. Lasky, of the New Mexico Bureau of Mines, is in Washington, D. C., assisting G. F. Loughlin to prepare a report on the Magdelena mining district.

L. C. Graton gave an address in New York on January 14 before the Mining and Metallurgical Society of America on "Some Economic Aspects of the Copper Industry."

L. H. Adams addressed the Washington Academy of Sciences at its December meeting on "The Creation of the Earth and Its Early Development."

The 229th meeting of the Washington Academy of Science was held at The National Museum in Washington on the evening of January 14

The retiring president, Ales Hrdlicka, gave an address on "Organic Evolution," the second of a series of lectures on Origin and Evolution by different scientists, to be published later in book form.

The U. S. Department of the Interior announces the discovery in Texas in the 12th test hole, of potash minerals not previously found in Texas. They are carnallite ($KCl.MgCl_26H_2O$), sylvite (KCl), langbeinite ($K_2SO_4.2MgSO_4$), and kieserite ($MgSO_4H_2O$). These have been found previously in New Mexico, however. This discovery raises the question whether the New Mexico area of patash chlorides extends into Texas, or whether a new series has been discovered. The potash chlorides and langbeinite of the 12th test are not in commercial quantities.

The Empire Mining and Metallurgical Congress will hold its third meeting in south Africa from March 24 to May 9, 1930, beginning and ending at Cape Town. There will be excursions to mining centers in the Union and in the Rhodesias, and technical papers will be presented. Reduced fares have been arranged on steamship and railroad lines. Further information may be obtained from the Secretary, Box 4604, Johannesburg, South Africa.

The Geological Society of America held its fifty-second Annual Meeting in Washington, D. C., on Dec. 26 to 28, 1928. It was the largest registration to date. The meetings were held at the commodious Wardman Park Hotel, which proved unusually congenial and satisfactory. The members met, held committee and sectional meetings, lived, and ate, under one roof. Some 76 titles were offered in the meetings; 29 by the Mineralogical Society and 27 by the Paleontological Society. The Society of Economic Geologists did not hold a meeting at this time; their technical meeting will take place this spring. There were three addresses: one of welcome by George Otis Smith; the retiring presidential address of the G. S. A. by Heinrich Ries, on "Some Problems of the Non-Metallics"; and that of the retiring president of the Mineralogical Society, A. L. Parsons, on "Iridescent Color in Peristerite."

After the banquet the Pick and Hammer Club enlivened us with one of their entertaining musical shows, with humorous and pat take-offs on several of the members.

The Washington geologists are to be congratulated for arranging an unusually interesting meeting that only Washington could supply.

Professor E. Harbort of the Technische Hochschule, Berlin-Charlottenburg, well known for his contributions to the geology of the German salt domes, died suddenly Dec. 14, 1929.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.

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